THE PRINCIPLES OF ANATOMY AS SEEN IN THE HAND

THE LESSON IN ANATOMY. (*Rembrandt.*)

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AS SEEN IN THE HAND

BY

FREDERIC WOOD JONES

D.Sc., M.B., B.S. Lond.

PROFESSOR OF ANATOMY IN THE UNIVERSITY OF ADELAIDE; SOMETIME PROFESSOR OF ANATOMY IN THE UNIVERSITY OF LONDON, AT THE SCHOOL OF MEDICINE FOR WOMEN; EXAMINER IN ANATOMY TO THE UNIVERSITY OF LONDON, THE CONJOINT BOARD OF THE ROYAL COLLEGES OF PHYSICIANS AND SURGEONS, AND TO THE SOCIETY OF APOTHECARIES

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TO MY WIFE

PREFACE

THIS volume owes its inception to several circumstances. First, it is the result of attempting to teach medical students such principles of anatomy as may be expected to interest them in their school work and assist them in their after-life as practitioners of medicine. But more immediately its origin is due to the necessity of choosing some circumscribed study in applied anatomy as a subject for a series of lectures. These lectures were given as a part of the Course of Instruction to officers of the R.A.M.C. at the Special Military Surgical Hospital, Shepherd's Bush. The product of these circumstances is not designed, as were the lectures, for qualified medical men, for it is hoped that the student of anatomy, no matter if he be definitely following a career of medicine or not, may obtain some help from its pages.

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CHAPTER I.

The Hand as an Anatomical Study.

Some years ago it was by no means uncommon to hear medical men express the opinion that Human Anatomy, as a subject for scientific research, had been exhausted long ago. And indeed, when one compares many modern works upon the subject with the products of the Golden Age of Anatomy as Andreas Vesalius established it in 1543, it seems that the intervening centuries have produced but little save the invention of the colour process for the reproduction of illustrations. Human Anatomy has appeared to many as a subject in which advance was impossible, and it must be owned that compared with the younger branches of Physiology, Pathology, and Biology, it offered but few attractions in the way of unsolved problems to any man determined to devote his energies to the scientific side of medicine. Anatomy has suffered in consequence, and in England especially there has been a tendency for it to fall behind in the wonderful march of progress that medicine has made during the last half-century. Some, not content with regarding it as an exhausted subject, have attempted to minimise its utility to the medical practitioner, and even its most enthusiastic teachers must admit that from legislative neglect, and from failure to appreciate its importance by those responsible for the ordering of Education in this country, its practice and its proper advancement have been very seriously hampered.

But the last few years have brought great changes. Those who imagined that the structure of the human body presented few problems received their awakening with the arrival of the very first convoy of men wounded in the War. A great demand for knowledge of Anatomy arose, and the demand was made not only by those in whose surgical care the wounded were placed in our hospitals, but by the very large number of enthusiastic medical helpers that the War has brought into

existence. The War has done away, and, let us hope, for ever, with that type of medical man who, knowing but little anatomy, affected to despise it as useless knowledge. It has relegated to well-deserved obscurity the surgeon who boasted—even if he did not believe—that a knowledge of anatomy was of but little use to the skilled operator. War surgery is practical anatomy,

FIG. 1.—In this drawing the right foot is placed upon the left leg, and the right arm shows anatomical peculiarities.

and the medical man whose knowledge of anatomy is so slender that it may not be turned to practical use has been forced either to learn more, or to turn his hand to some auxiliary mode of treatment of the wounded in which he does not tamper with, nor need to understand, the structure of the human body. Anatomy has come into its own, so far as its proper appreciation by the medical man is concerned. Even there are hopes, judging from Sir George Newman's Memorandum on Medical

Education,* that it may ultimately receive proper recognition from our educational legislators.

There are problems in Human Anatomy and methods in Human Anatomy, and it may be that, without a complete examination of the human body, these problems and methods may be illustrated by the study of a single member. Anatomy can only be studied completely in the dissecting room, or in the operating theatre ; but much may be learned elsewhere. The medical student, with the special advantages afforded by the schools of Anatomy, is apt to forget how important is that study of the human body that can be made without the aid of scalpel and forceps. Surface Anatomy is always rather a tender spot with the examination candidate. But Surface Anatomy may be studied at all times and in all places. All that is needed is an aptitude for observing. There is a danger that in the complexity of modern medical education the hope of the older educationalists may not be fulfilled, and that the curriculum may tend to produce a well-taught, but wholly unlearning, individual. Education that does not beget a power of observation is of little use in practical medicine. Although the multitude of modern instruments of precision has rather set in the background that older type of physician who, depending upon his own powers of observation alone, developed the mixed attributes of a Sherlock Holmes and a Boy Scout, the man who seeks success in Medicine does so in vain if he remains unobservant. But conspicuous powers of observation are none too commonly displayed by medical students. It is in the Anatomy Department that whatever gift of observation the student may possess should receive its fullest cultivation. The student must be taught to learn, and to learn anything that is useful in the practice of medicine a faculty for accurate observation is essential. There are very few parts of the human body in health or in disease that repay observation better than the hand. To one who is observant the hands of his fellow-men are a source of perpetual interest, and there is no reason why a monopoly in this interest should be permitted to pass into the keeping of those folks who regard the hand merely as an object by which fortunes may be

* "Some Notes on Medical Education in England," Board of Education, 1918.

told. The casual way in which some artists regard hands and feet finds its expression in the work not only of the lesser ones, nor even in connection with illustrations altogether devoid of any attempt at reproducing precise anatomy. Rembrandt himself is among the culprits, wonderful anatomist though he was, for in his famous "Lesson in Anatomy" Nicholas Tulp is represented displaying the superficial flexor muscles of the fingers arising from the radial condyle of the humerus (see *Frontispiece*). It would appear that Rembrandt must have drawn the details of anatomy from a right arm, and then have transferred them to the left arm of his wonderfully realistic subject. There are many who admire this great work and yet fail to notice this very strange anatomical error. Our text-books of anatomy could also be made to stand in the pillory, but the subject is a delicate one, and it will be enough to mention that the phalangeal formula of 2 . 3 . 3 . 3 . 3 . (which is discussed later) has notoriously been altered to 3 . 3 . 3 . 3 . 3 . with very striking pictorial results. The pages of our magazines and the illustrated advertisements teem with the most curious anomalies, and any one can find them for himself with but little trouble. The samples reproduced here (Figs. 1, 2, and 3) are taken at random, and I am unable to acknowledge their source, which is, perhaps, a fact not altogether to be regretted. But, quite apart from such glaring instances as these, minor evidences of lack of observation will be found with astonishing frequency.

Fig. 2.—Seated figure with crossed legs in which the right and left feet are reversed.

The hand as the expressor of emotional states affords a study in itself; it is a study that the physician cannot afford to neglect, and it is one to which some artists have given insufficient attention. The "expression" of the hand is a thing impossible to define, and yet it is a very real factor. It is more easily noticed by its absence; and it is often very astonishing to see how utterly unlike the real hand is even the most perfect plaster cast.

The hand then presents excellent opportunities for the student of human nature and of human anatomy to exercise his powers of observation, and to study the outward form of a portion of the body. But more to our purpose is the fact that in probing deeper into the anatomy of the hand we are immediately brought face to face with some of the most important biological problems and some of the most striking exhibitions of general vital principles. It is for this reason that the hand has been selected as a limited and self-contained study from which the student may learn more of principles and less of details than is usual in complete text-books of anatomy. We cannot go far in the study of the hand, even if we limit ourselves to a mere examination of its surface, before we are forced to notice some facts which bear upon that ever present problem, the question of our own origin. Man's place in nature is largely writ upon his hand, and many of the simplest and most familiar details of homely knowledge become important when we examine our hands with the critical spirit we would adopt towards the members of some strange and uncommon beast. In the hand are bones, joints, muscles, arteries, veins, and nerves, and in connection with each of these we may find, within a limited compass, evidences of those general principles which prevail throughout the animal body. One other thing will strike the student who considers with any real attention the many-sided complex of structure and function as it is displayed in this one small member. He will realise that, despite the accumulated work of the past four centuries, much is uncertain, much remains unsolved, and much remains absolutely unguessed

Fig. 3.—The right hand is placed upon the left arm.

at, even when we consider the most familiar features of our most familiar member.

Here we cannot enter into the pathological conditions of the hand, nor even discuss the hand as revealing general pathological states, for we are concerned solely with normal anatomy.

CHAPTER II.

Pentadactylism.

It might seem unnecessary to make comment upon the fact that both the human hand and foot possess five digits ; and yet this condition of complete pentadactylism is one of great interest and some distinction.

In discussing the problems connected with the numerical digital series it will be necessary to adhere to a precise system of nomenclature for the five elements, and in all cases in which they are alluded to merely as digits, and without regard to their distinction as special members of either the hand or the foot, they will be numbered from 1 to 5, counting from the middle line of the body outwards when the limb is placed with the nails directed upwards, or, in more precise language, counting from the preaxial to the postaxial margin of the limb.

Many of the digits, however, have familiar distinguishing names. Thus the first digit of the hand is the thumb, or pollex ; the second, the index, or fore-finger ; the third, the medius, or middle finger ; the fourth, the annularis, or ring finger ; and the fifth, the minimus, or little finger. An older name for the fifth digit of the hand is auricularis, or the finger used for inserting into the ear, but this name is practically obsolete, and will not be used here.

Upon the foot only two digits are familiarly named, the first being the hallux, or great toe, and the fifth being the little toe. It is of the first importance that the confusion between first finger or toe and first digit be avoided, and to this end the expressions " first finger " and " first toe " will never be used.

Familiarity with human pentadactylism has not lessened the speculative interest of the morphologist in the great question of the primitive or secondary nature of this arrangement. This is a subject upon which there is room for much speculation and debate.

Are we to assume that the oft-recurring presence of five digits

in the manus and pes of the vertebrate series represents the most primitive type of digitate member, or has the number five been evolved by the reduction, or the increase, of some more primitive formula? Upon this point there is great diversity of opinion. No one, so far as I know, has ever suggested that the digitate member formerly possessed a smaller number of digits than five, and, indeed, there are no grounds, anatomical or paleontological, for imagining that the five fingers and five toes of man have developed from an originally more limited series. Yet, despite this fact, anatomists have sometimes regarded the five-rooted limb plexus of the human fore limb as a development from the simpler type prevailing in those animals, such as the Ungulates, which, being truly quadrupedal, have a reduced digital series. Such a line of argument is quite illogical, and is merely the outcome of that mental bias which regards all human structure as the perfected type the imperfect stages of which are to be seen in lower mammals. Arguments based upon such reasoning are often attended by poor success, and doubtless will be subjected to a more rigid scrutiny with the passage of time.

That the pentadactylous condition has been derived from some form in which the digits were originally more numerous is, however, a widely held opinion. Certain facts appear to lend support to this view. It is true that five digits is the normal maximum for all the existing Amniota, but some forms possess rudiments of what is usually regarded as an extra digit. Again, certain elements not rising to the dignity of rudimentary free digits are commonly present in the carpus and tarsus of all classes of Amniota. Extinct forms showing more than five rays in the extremities are known, and these lend weight to the supposition that some number greater than five may have constituted the ancestral type. Then, too, abnormal supernumerary digits have been recorded in a wide range of animal types from man downwards.

Finally, if the higher vertebrate limb has been derived from the many-rayed fins of fish, then it is natural to suppose that a considerable numerical reduction has taken place in the evolutionary story of the digits.

How many digits were present upon the ideal prototype of the manus and pes is by no means agreed upon by the supporters of primitive polydactylism; but most authorities (Bardeleben, Wiedersheim, etc.) are inclined to the belief that seven represents the ancestral number, and there are good grounds for this choice. But before we may reach agreement upon the precise number it is necessary to review the facts which lend support to any belief in the theory of ancestral polydactylism.

(1) In addition to the more stable elements of the carpus, there are other, smaller, bones which occur upon the radial and ulnar sides of the wrist. These bones, though commonly termed the radial and ulnar sesamoids, are often regarded as true carpal bones, despite the fact that they are associated with the tendons of the radial and ulnar flexors of the wrist. One, the familiar pisiform, is present upon the ulnar side of the cuneiform, and the other, the rare os radiale externum, upon the radial side of the scaphoid. It is these two elements which have generally been singled out as the representatives, in very rudimentary form, of two lost digits, the one named the post-minimus and the other the pre-pollex. In the tarsus the occasional bones known as the tibial sesamoid, or os tibiale externum, associated with the tendon of the tibialis posticus, and some other more rarely occurring elements have been regarded as the debased remnants of a pre-hallux; while the equally infrequent os calcaneus accessorius, os peronæum, and os Vesalianum, associated with the peroneal tendons, have been taken to represent a lost post-minimus.

With regard to this evidence it must be noted that, with the exception of the pisiform bone, additional carpal and tarsal elements are exceedingly variable in the precise site and form of their occurrence. There is no doubt that in certain of these occasional elements there is very tempting material from which to reconstruct lost digits, but it must also be remembered that, besides those which fulfil this *rôle* so well, there are many others which, in order to satisfy their claims, would demand a belief in a very high degree of ancestral polydactylism. Pfitzner, who has made an exhaustive study of the carpus and tarsus, has increased the generally recognised seven human carpal

elements to a total of thirty-three, and the seven tarsal elements to eighteen, by the inclusion of all the occasionally occurring separate bones. Upon the whole the evidence points to the fact that these elements are adventitious, or, as Professors G. B. Howes and J. P. Hill have declared, " the most recent inquiries into these structures have shown them to be in the highest probability distinct *sui generis* from the normal digits of the pentadactyle limb, if not from each other." * Again, the work of Carlsson has shown that there is " good reason for believing that the marginal nodules of the mammalian pes are progressive rather than vestigial in nature." It must also be remembered that fractures of the carpal bones are by no means uncommon, and that these fractures do not unite. In human anatomy this is a point that needs to be taken into consideration, since small bones described as additional elements may at times be in reality broken and un-united portions of the ordinary carpal elements (see Fig. 4).

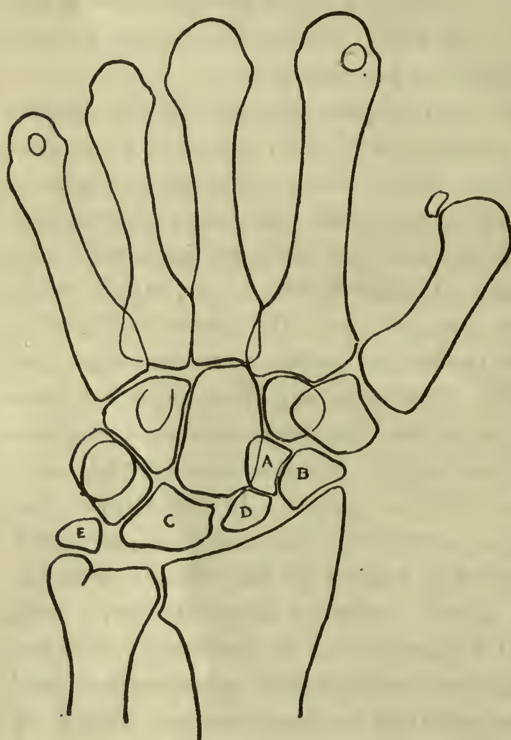

FIG. 4.—Tracing from an X-ray plate of a case of old standing fracture of bones about the wrist. The scaphoid is divided into two separate bones A and B, the semilunar into C and D, and the styloid process of the ulna is separated as E.

One other structure in the human wrist has been taken to represent in part the lost post-minimus, and this teaching is

* On the pedal skeleton of the Dorking Fowl, with remarks on Hexadactylism and Phalangeal variation in the Amniota. *Jour. Anat. and Phys.*, Vol. XXVI., pp. 395—403.

mentioned here solely for the reason that it sometimes constitutes a part of the medical student's stock-in-trade of those oddments of anatomical lore which, classed together, compose the science of morphology. The structures known as interarticular fibro-cartilages have ever offered an almost irresistible temptation to the morphologist. There is no inter-articular cartilage in the human body that has escaped the morphologist and failed to have an explanation of its presence furnished by the investigation of some structure in a lower animal, and often it has mattered but little if the type of lower animal selected has no conceivable phylogenetic association with man. There can be but little doubt that the selection of the triangular fibro-cartilage of the wrist joint as the monument of a lost post-minimal digit (Corner) is one of the unfortunate ventures of morphology, and it is worth while turning aside to trace the history of this structure as it is actually seen in certain mammalian types.

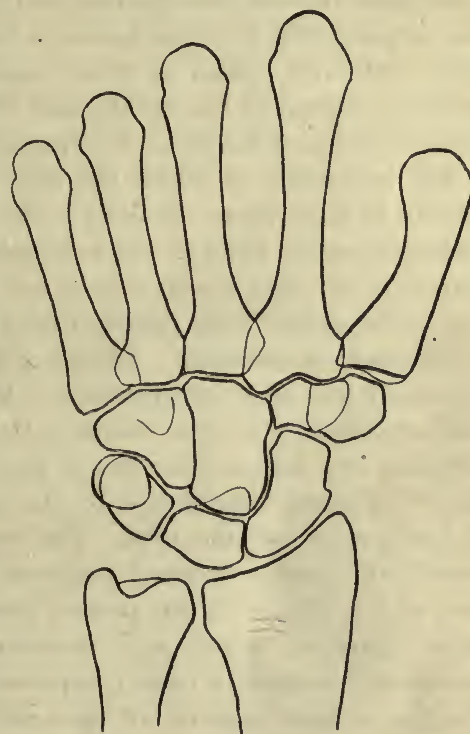

Fig. 5.—Tracing from an X-ray plate of a normal hand. Note the separation of the lower extremity of the ulna from the bones of the carpus.

In a typical mammal in which both bones of the forearm are well developed, and free to rotate in the action of pronation and supination, one joint exists between the upper ends of the radius and ulna and another between their lower ends, to permit of this rotation. In such an animal the hand may be bent backwards and forwards, flexed and extended at the wrist joint;

but it can be moved sideways, adducted and abducted, to only a very limited degree.

These conditions are realised in animals whose life activities make but simple demands upon hand movements ; and the bears may be taken as typical of such a functional stage.

In these animals both the ulna and the radius articulate with the carpal bones, the ulna having a rounded, cartilage-covered lower extremity which is on the same level as the inferior articular surface of the radius, and which articulates with the ulnar elements of the first row of carpal bones.

But in animals in which the hand is needed for a greater variety of movements, entailing a free power of adduction and abduction of the hand at the wrist joint, the lower articulating surface of the ulna becomes more and more reduced, the ulnar side of the carpus being liberated from the close bondage of the ulnar-carpal articulation. In the Primates these stages are extremely well seen, for whereas in a Macaque monkey the ulna still articulates over a wide area with the cuneiform, the ulnar articular area becomes far less in the higher Primates, and in Man it is merely represented by the apex of the non-articular styloid process of the ulna. The human styloid process is merely the greatly reduced rudiment of the carpal articular area of the ulna. As this process goes on, the inferior radio-ulnar ligament, which is a derivative of the interosseous membrane, becomes a more conspicuous factor, and in Man it develops a small amount of fibro-cartilage, known in human anatomy as the triangular fibro-cartilage, which binds the base of the former ulnar carpal articular area to the radial carpal articular area. A glance at the radiograph of an adult hand will show how surprisingly far the articular surface of the cuneiform is removed from the styloid process of the ulna, and from the triangular fibro-cartilage, and will convince any one how wrongly most wrists are articulated in museum skeletons (see Fig. 5). The upper articular facet of the cuneiform glides over the internal lateral ligament of the wrist joint in most habitual movements of the hand, and on to the triangular fibro-cartilage in acute abduction ; it, therefore, forms one of that most interesting group of articulations (comprising the facet

PLATE II.

X-ray of a hand in which the styloid process of the ulna forms an articulation with the cuneiform bone of the carpus (indicated by the arrow). Note also the sesamoid bones at the metacarpo-phalangeal joints of thumb, index and minimus.

on the lower surface of the head of the astragalus and the facet on the postero-lateral aspect of the same bone, etc.) in which bone articulates, not with neighbouring bone, but direct with specialised ligaments. The condition in the human embryo, however, is very different, for here the lower articular facet of the ulna is well developed and shares in the articulation with the carpus, just as it does in the bears. As a very rare anomaly this condition may persist in the human adult (see Plate II.). This, then, is the story of the triangular fibro-cartilage and the styloid process of the ulna: There has been a shrinkage of the human ulna from the carpal articulation, and the inferior radio-ulnar ligament has become exposed so as to form an integral part of the joint surface, the articular area of the ulna having become reduced to a mere non-articular spur. This change is brought about by the demand for increasingly free movements of the hand upon the forearm; and it becomes impossible to read into this story any probability of the disappearance of a post-minimal digit into the triangular fibro-cartilage.

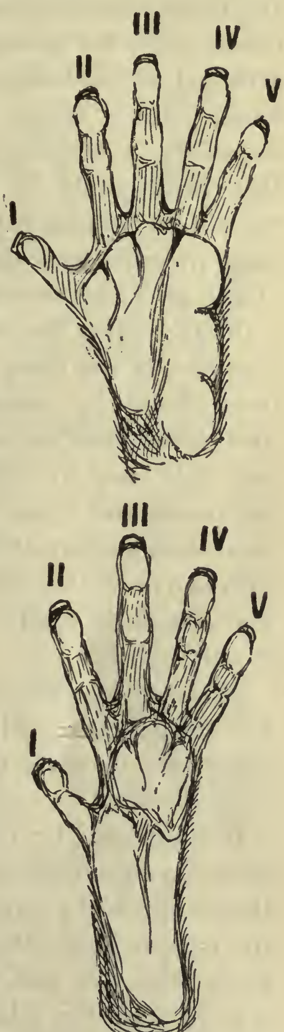

Fig. 6.—The full set of digits of a comparatively unspecialised mammalian type.

The evidence of the previous normal existence of a pre-pollex and a post-minimus which Bardeleben and Fick have derived from a study of the muscles of the hand and foot appears to be no more conclusive than that deduced from the presence of occasional marginal bones n the carpus and tarsus. The presumption that the flexores carpi radialis and ulnaris and the abductors of the first and fifth digits are muscles of pre-pollex and post-minimus depends

for its acceptance on a belief in the morphological significance of the marginal carpal elements to which they are attached. We must admit the soundness of the theory as applied to the bones before we attempt to extend it to the muscles which are attached to the bones. Neither does Fick's anomalous human muscle—the "flexor præpollicis"—carry conviction, for the instability of the intrinsic muscles of the hand is so familiar that there would be no end to theories did one attempt to explain on phylogenetic lines the whole of the occasional and quite irregular muscular slips seen in the hand during the course of a single winter session in any school of Anatomy.

(2) It is upon the occurrence of cases of additional digits in man and in the lower forms that a great deal of reliance has been placed by upholders of theories of phylogenetic polydactylism. But some caution is needed. Generally one may say it is easy to overdo the building of theories of normal phylogeny and ontogeny based upon studies of what are pure anomalies, malformations, or freaks. Babies are sometimes born with two heads, but this fact affords no safe grounds for believing that our single head has been derived from a former condition of polycephaly.

Then, again, digits are serial members, and it is notorious how freely nature adds to, or subtracts from, serial organs without regard to any general underlying tendency, either atavistic or progressive.

It must also be remembered that real additions are most easily made to the ends of the series, and the new member will therefore tend to be placed before the normal first digit or after the normal fifth. But in the case of fingers and toes another factor comes in, and this factor enjoins a caution beyond that derived from the other considerations. It has been shown by human anatomists studying human polydactylism and by zoologists working at polydactylism in lower forms (Howes and Hill) that an increase in the number of digits may be due, not to the addition of digits to the series, but to the fission of digits normal to the series. The normal digit may be split longitudinally into two. The puzzling additional toe which is present in the Dorking fowl, and which was previously determined

to be a real pre-hallux (Cowper), has been shown conclusively (Howes and Hill) to be due to the cleavage of a normal digit. We may say therefore that the evidence to be derived from anomalous cases of extra digits has to be submitted to a very rigid scrutiny before we jump to the conclusion that it truly indicates an ancestral condition in which the possession of more than five digits was normal.

(3) It would naturally be thought that, were a phylogenetic reduction of the number of digits to have taken place in the evolution of the Vertebrates, clear light would be thrown upon the process by the study of paleontology. From the study of the limb of the horse any one would arrive at the conclusion that the digital series had at one time been more numerous than it is to-day. Without the evidence derived from the study of extinct forms any comparative anatomist would be prepared to believe that modern horses had fewer digits than were possessed by the earliest members of the stock from which they sprang. As every one knows, this supposition is borne out in every way by the well-known series of extinct ancestors of the existing Equidæ.

Fig. 7.—Reduction of digits to $\frac{4}{4}$ by the loss of the first digit on the pes. From *Felis concolor* (after Pocock).

Paleontology clearly shows the reduction from five digits to a single digit which has taken place in the evolution of the horse. Does it show the reduction from some larger number to the maximum of five in the evolution of the higher orders of the vertebrates? So far no such phylogenetic

series has been unearthed by the paleontologist. It is true that paleontology has proved that the digitate limb may possess more than five digits, but that is a very different thing from demonstrating that any number greater than five represents a basal or primitive condition, for it is possible that the increased number might be due to a secondary specialisation. The evidence so far available would seem to point to this possibility as being the true explanation. We shall see later how other anatomical features show a high degree of undoubted specialisation in limbs adapted as swimming organs, and we may conclude in agreement with Howes and Hill "that current research in paleontology is bringing us more and more to the conclusion that the Enaliosaurian paddle, so often invoked by the defenders of polydactyle limb theories, is the specialised derivative of the pentadactylous limb of a land reptile" (*op. cit. supra*).

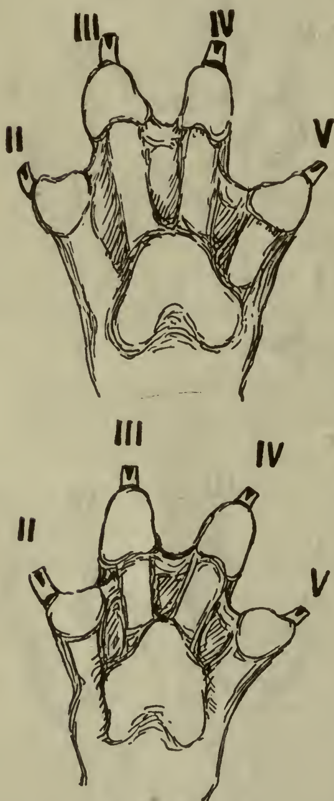

Fig. 8.—Reduction of digits to 4/4 by the loss of the first digit on manus and pes. Form *Hyæna striata* (after Pocock).

From a consideration of all these facts we are forced to the conclusion that the evidence in favour of the pentadactyle limb being the evolved product of an ancestral hepta- or hexa- dactyle type is by no means strong. Even if such a derivation of the normal five digits from a previously larger series be arguable from the data at present available, it must be admitted that the establishment of the pentadactyle condition is extremely ancient. Fick admits that it is highly improbable that the primitive mammal possessed a true pre-pollex; and just as one knows that the mammals had for their birthright seven vertebræ in their necks, so one may feel practically certain that

limbs bearing five digits were part of the make-up of the basal mammalian stock. In his five fingers and five toes Man therefore displays a condition which, from all the evidence available, we are justified in assuming is the absolute bed-rock of mammalian primitiveness. Since it does not greatly affect our present purpose, we need not press this finding further, but to assume that the numerical series of human digits represents the most primitive plan of the vertebrate digitate limb should not place an undue strain upon our credulity.

Fig. 9.—Reduction of digits to $\frac{2}{5}$. The remaining functional digits are III. and IV.

So much for the interest of Man's pentadactyle hand and pentadactyle foot. There is also a distinction in this condition which is rather apt to be overlooked. Man has five functional digits upon each member, and the only digital specialisation which he shows is the possession of a larger and more mobile digit upon that border of the limb which is nearest to the middle line of the body. The special character of the human great toe and little toe will be discussed later. Here we are concerned only with the general fact that none of our digits are reduced to an absolutely rudimentary condition, and none are specialised in any very definite way except the thumb and great toe. The evidence of paleontology makes it clear that the specialisation of the inner digits is as old as the mammals, and therefore the human thumb and great toe in their essential features do not rob the human hand and foot of any degree of their basal mammalian primitiveness. But although Man retains this mammalian birthright with but little alteration, very many of the existing mammals have modified it very completely by different specialisations, and are therefore in this feature less primitive than Man. All the anthropoid apes, except the syndactylous Siamang Gibbon, show human simplicity of hand and a more than human simplicity of foot.

All the Old World monkeys present the same feature except the genus *Colobus*, in which the thumb is either extremely reduced or altogether absent. The New World monkeys lack the typical mobility of the thumb, and in the genus *Ateles* the thumb is altogether absent, as in *Colobus*, reducing the digits of the manus to four. In the Lorisine section of the Lemurs there is also a tendency towards reduction of the digits of the manus, but here the dwindling (*Loris*) or absent (*Perodicticus*) member is the index finger, the thumbs and big toes being always well developed and mobile. In all the Lemurs also there is a tendency to specialise the second digits of the feet by elongation and by the development of specialised nails. Amongst the Insectivora pentadactylate hands and feet are the rule, but the pollex and hallux are but little specialised and possess no mobility not shared by other digits.

Some members of the Carnivora retain five digits upon both limbs, while some retain five on the fore limb, but have lost the hallux from the hind limb, and others have lost both hallux and pollex. In no case is pollex or hallux specialised in development or mobility.

Many Rodents possess the typical five fingers and toes, but many have five digits on the fore limb and only four on the hind limb, the hallux being rudimentary. Some have lost the pollex, but retain five hind digits. Some have four digits on both hind and fore limbs, and some are reduced to four on the fore limb and three only on the hind limb. The pollex and hallux show special development, and probably special mobility, only in certain arboreal mice.

Among the Ungulates digital reduction reaches its maximum, the single functional digit of the horses being familiar to every one.

Nearly all the Edentates show digital reduction, but a few species retain five functional digits upon each extremity without specialisation of the first or inner digits. It is not until the Marsupials are reached in descending the mammalian scale that some few animals are again met with in possession of five fingers and five toes of which the innermost members are specialised. Even in these forms it is only the hallux which shares the peculiar mobility which we have every reason to

regard as being primitive. The most lowly of all mammals—the Prototheria—show the primitive number of digits, but in all living species the manus and pes have otherwise lost many primitive characters.

We therefore see that, although the possession of five fingers and five toes is an oft recurring phenomenon among the mammals, it is only in a comparatively small number of genera in certain of the great mammalian groups that this simple condition is retained. Some members of the Insectivora, some of the Carnivora, some of the Rodentia and Edentata among the Eutheria, some of the Metatheria, and the two types of Prototheria are the only living mammals besides the Primates which possess what we believe to be the primitive number of digits. All the other members of these orders, and all the members of the remaining orders, are specialised away from this primitive condition. More than that, Man stands alone with the Primates and certain Marsupials in possessing at least one inner digit particularly mobilised, and finds his equals in the display of a "thumb" only among a certain section of his own group. The human condition of complete pentadactylism is therefore a very noteworthy feature, a feature which stamps this part of Man's anatomy with the Hall mark of primitiveness and a feature which a great host of other mammals has lost by specialisation leading to a reduction of their digital series.

Fig. 10.—Reduction of digits to $\frac{1}{1}$, the remaining functional digit being III.

It is rather a remarkable thing that, since every student of nature must be struck with the unvarying tendency for complete pronograde quadrupedal habit to effect a reduction in the digital series, it should so commonly be believed that pentadactylous Man has descended from typical pronograde quadrupedal ancestors. There is but little need to-day to dwell upon this illogical trend of thought, for such topsy-turvy interpretations of comparative anatomy are rapidly becoming things of the past.

CHAPTER III.

THE DIGITAL FORMULA.

DIVERSE animals which possess the common bond of retaining five fingers and five toes may yet have these digits so differently arranged that they present very dissimilar types of hands and feet. The general form of the member will be in the main determined by the relative development of the different digits in the series, and by the contour of the bases from which they spring. It is in the length of the different digits far more than in the contour of the digital margin of the palm or sole that variation is displayed. The developing limb of all the Amniota appears at first as a small outgrowth from the side of the body. This outgrowth, known as the limb bud, takes the form of a little fleshy paddle with a rounded free edge. It is from the rounded edge that the digits grow outwards in a radiating manner. It is obvious that, if all the digits are of equal length, the middle one will project ahead of the others ; those standing next upon either side of it will not reach quite so far forwards, and the digits situated upon the two extreme edges of the palm or sole will have their tips still further behind. This is a very primitive contour, and to express it we may make a numerical statement expressing the relative forward extension of the tips of the digits when the member is laid flat and maintained in the long axis of the limb. Such a numerical statement I have termed the *digital formula*,* and it must be remembered that such a formula does not express the relative lengths of the digits, but the relative projection of tips of the digits from the extremity of the limb. In the ideal case that we have pictured the actual digits are all supposed to be of the same length, but the digital formula would be $3 > 4 = 2 > 5 = 1$, assuming that the contour of the end of the limb presented a perfectly even curve and the digits were arranged symmetrically around the curve.

* See "Arboreal Man," Edward Arnold, London, 1916

Very early in the vertebrate series this formula becomes modified, for the first digit tends to be situated further back along the curve on the inner border of the limb than the fifth is upon the outer border of the limb. The formula now becomes

Fig. 11.—Type of hand in which the index finger is relatively short. The formula for the digits is $3 > 4 > 2 > 5 > 1$. The measurements are taken from the hand of a woman.

$3 > 4 = 2 > 5 > 1$; this expresses the condition found in a large number of pentadactyle vertebrates representative of Amphibia, Reptilia, and Mammalia, and it may be regarded as being the most primitive condition that prevails among living animals. This is the formula which fits the description given

by many artists and anatomists of the typical or ideal human hand.

For a standard description of the human digital lengths we may take that given in a modern book, the conjoint work of artists and anatomists: * " The middle finger is the longest, and

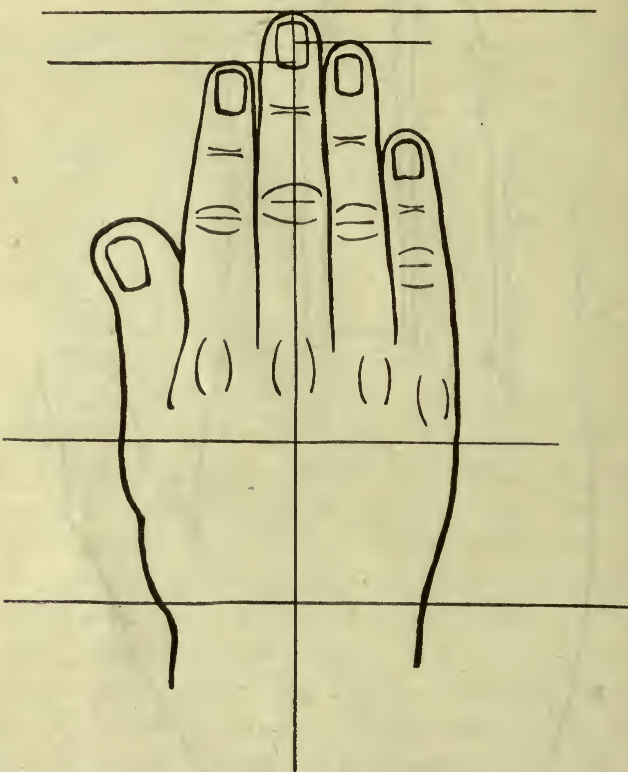

Fig. 12.—Albert Durer's canon for the proportions of the hand. Formula $3 > 4 > 2 > 5 > 1$. (From " Della Simmetria de i corpi humani," 1591.)

the ring and index fingers are commonly of equal length " (*i.e.*, $3 > 4 = 2$). Thus, taking an accepted standard for the human digital formula, we find that Man exhibits a most astonishing degree of basal vertebrate simplicity in the architecture of his hand. But the inspection of only a very small number of hands will at once show that, though the ring and

* " Human Anatomy for Art Students," Sir Alfred Fripp and Ralph Tompson, London, 1911.

index fingers are often of equal length, they are not by any means always so. Either may outstrip the other in length, but never so completely as to be in advance of the middle finger. Both of these variations are of the very greatest interest. They would be represented by the formula $3 > 4 > 2 > 5 > 1$ in the case where annularis was dominant, and by $3 > 2 > 4 > 5 > 1$ where the index was the longer of the two. The first formula is of common occurrence among the pentadactyle mammals, and it is especially characteristic of arboreal animals, both eutherian and metatherian, which retain a considerable number of primitive features in the anatomy of their hands.

The primitive little mouse-like Phalangers of the genus *Dromicia* have their fingers arranged in this way, and so have several less interesting forms, but the importance of this formula for the student of human anatomy lies in the fact that it is typical of all monkeys and apes. Did we belong to that school which finds in such things some stigma of degeneration or lowliness, we might condemn the hand which has the short index finger as distinctly simian. Both the clinician and the palmist have directed their attention to this point.

It is to be noted that this type of hand is rather the result of shortening of the index finger than of lengthening of the annularis, and in many cases the condition when markedly developed is accompanied by a particularly "weak" thumb.

For the comparative anatomist and the student of human phylogeny there is another interest in the formula $3 > 4 > 2 > 5 > 1$. This is the plan of the simian hand, but it is also the plan of the hand of that remarkable little animal known as *Tarsius spectrum*; but in *Tarsius* the annularis only very slightly exceeds the index. *Tarsius* is almost universally regarded by zoologists as being a somewhat atypical Lemur. In this very obvious feature, as in so many more deep-seated details of its structure, *Tarsius* shows a condition that can only be termed primitive simian and distinctly non-lemurine. All the lemurs, Asiatic, African, and Malagasy, have their hands built on very distinctive lines, and all have the annularis as the largest member of the series. The lemurine formula

is $4 > 3 > 5 > 2 > 1$. The dwindling index and dominant annularis are characteristics of the lemurine hand, and it is important to note how different in plan is this hand from the more primitive type characteristic of the Simiidæ. Taking this single point for what it is worth, it would certainly seem that the simian hand was not evolved from the lemurine type; and that *Tarsius* found its affinities with the monkeys rather than with the lemurs.

Fig. 13.—Palmar surface of the right hand of a Rhesus monkey to show the typical simian proportions of the digits, $3 > 4 > 2 > 5 > 1$.

The lemurine formula has another interest, for, like the simian formula, its independent parallel has been evolved among the arboreal Marsupials, and the Flying Phalangers, *Petauroides*, and *Acrobates* display a hand constructed upon lemurine proportions.

The other type of human hand is of interest not so much from the point of view of speculative phylogeny, but from its importance as a human distinction. It is the type which is described by some anatomists (Humphry) and depicted by many artists as the normal human hand. In this distinctive "human" hand the formula is $3 > 2 > 4 > 5 > 1$.

The index is a long finger, generally being considerably more pointed at its tip than either annularis or medius, and practically always accompanied by a well-developed and more or less "expressive" thumb. This type of hand is definitely non-simian, and it constitutes a characteristic human specialisation. This specialisation is shown in far more details than the mere length of the second digit, for we shall have to discuss the distinction of the muscles and nerves of the index finger, as well as the peculiar creases upon the hand associated with this human development. Many have dwelt upon some of the separate outcomes of the human dominance of the index finger, and in a rather topsy-turvy way the human ability to point out objects has received certain attention, but there is a grave

danger of mixing up physical and psychical specialisations if the act of pointing is made the mainspring of the development. We will dismiss the subject here by noting that as a distinctive human characteristic the digital formula sometimes reads $3 > 2 > 4 > 5 > 1$, that this formula is found only in a certain number of cases, that it may be present in one hand and not in the other, that it depends upon the greater development of the index finger, and that it is definitely non-simian.

Interesting though this type of hand is as a human specialisation, it must be admitted that it constitutes a very slight departure from that condition of the manus which we have every justification for believing is the most primitive form of vertebrate hand known to us. With the human foot, however, the case is very different. Here the modifications are profound, and in no part of the human body are specific specialisations of greater interest.

Fig. 14.—Palmar surface of the right hand of a brown lemur to show the typical lemurine proportions of the digits, $4 > 3 > 5 > 2 > 1$.

The primitive digital formula of the vertebrate foot is similar to that of the hand. The middle digit is the dominant member, the marginal digits becoming progressively shorter towards either border of the limb. In the foot, as in the hand, the first digit tends to be placed further back upon the medial border of the limb.

This is the type of foot characteristic of the monkeys and anthropoid apes. The digital formula for the feet of the *Anthropoidea* is $3 > 4 > 2 > 5 > 1$, and is therefore exactly the same as the formula for the hand. But this is not the formula of the *Lemuroidea*, for their feet have been modified from the primitive type in just the same way as we have noted in their hands, and their digits are arranged after the plan $4 > 3 > 5 > 2 > 1$. Nor is it the digital formula for the human foot, for here the first digit is dominant, and there is

a progressive diminution of digits from first to fifth. The pedal digital formula which is typical of Homo as a species is $1 > 2 > 3 > 4 > 5$. Despite all argument to the contrary, and with all due respect to artists, bootmakers, and idealists, I remain convinced that if we were to set about the description of Man as a mammalian species we should include among his normal specific characters the elongation of the first digit in advance of any other members of the series. To do this is to run counter to those who consider that in the perfect human foot the second digit is extended in advance of the big toe. This is the type of foot which is sometimes called the "Greek Ideal." It is the one depicted in the work of most artists, and it is commonly regarded as the perfect human foot as it exists when untrammelled by boot pressure.

The boot pressure deformities of the human foot are well known, and they form so wide a field of study for the orthopædic surgeon that they (coupled with the fact that Greek is the dead language) have helped to foster the popular opinion that this useful member of society spends his time in setting to rights the distorted feet of the community.

But the typical human digital formula and the typical dominance of the human big toe cannot justly be ascribed to the human fashion of wearing some form of foot covering.

A tedious literature has accumulated about this question. There have been those who, anxious to minimise human distinctions, have asserted that the characteristics of the everyday human foot are caused by the pressure of the boot. Even there have been advocates for the teaching that the foot of the unbooted savage is but a very slight modification of the foot of the anthropoid ape. Erroneous teaching dies hard, especially when the teaching runs current with popular theories, and apparently one adds little to its decrepitude by critical analysis of its errors. Without such an analysis, and without specific reference to previous work, we will therefore make a series of assertions regarding the typical condition of the human foot.

The digital formula of the unbooted British "ragamuffin" child is similar to that of the booted perambulator of Bond

Street. Sir William Flower's examination of the feet of hundreds of the bare-footed children of Perthshire may be adduced

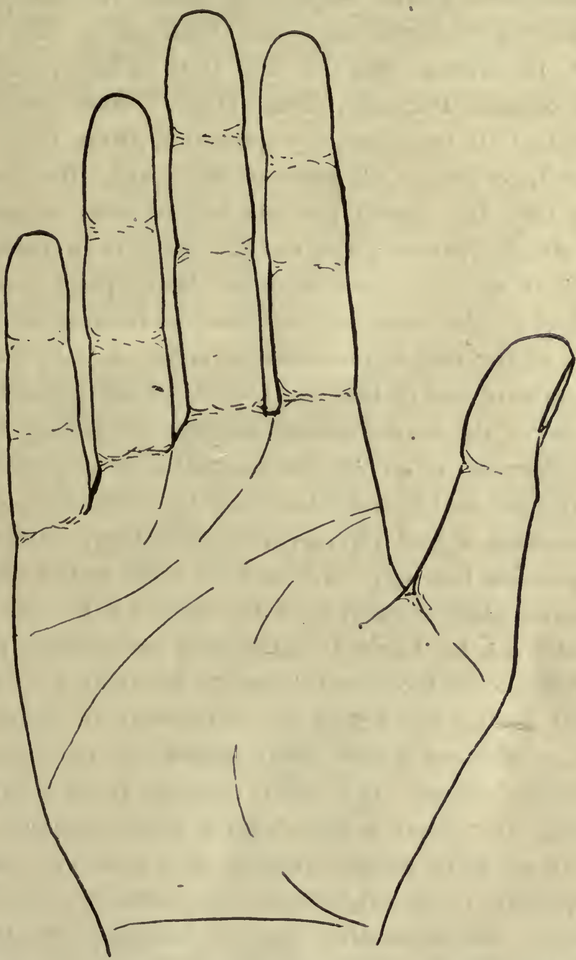

Fig. 15.—Type of hand in which the index finger is well developed. The formula for the digits is $3 \geqq 2 > 4 > 5 > 1$. The measurements are taken from the hand of a woman.

in support of this, for he found no case in which the big toe did not project in advance of the second toe.

The digital formula of the unbooted races is similar to that of the booted peoples. Every unbiassed traveller with a mind directed towards anthropology has noted this, and recorded observations extend to the most primitive members of mankind.

From personal observations I can confirm this for Chinese coolies, Japanese, Malays of widely different origin, Cingalese and various bare-footed natives of India, the inhabitants of Egypt, and the African races met with along the banks of the Nile in Nubia, and for the bare-footed population of Madeira, Spain, Portugal, and Italy. Such records could be multiplied to weariness by quotation from the works of observant travellers in all parts of the world. Besides all this, we know that the digital formula of the races of antiquity—such as the Egyptians—was exactly as it is in modern Man. Moreover, those who have ascribed the typical form of the human foot to the cramping influence of boots have neglected the study of the feet of new-born infants. A baby's big toe is just as dominant and its little toe is just as cramped and atrophic, as they are in the boot-wearing parents. Obviously either the acquired character of a boot-cramped little toe is being inherited, or the little toe and its neighbours on the outer side of the foot are undergoing a real phylogenetic reduction. Although the first supposition has been advanced by some as the explanation of the rudimentary condition of the baby's little toe, it is one that would not be likely to gain wide acceptance under the present influence of biological thought. It is rather a remarkable thing that during the period of controversy in which Huxley played so prominent a part this paradox was not submitted to the Huxleyan school. If it were true, as Huxley urged, that the human foot form resulted from boot-wearing, then the presence of an adult digital formula in a new-born baby must be proof positive of the inheritance of a character very obviously "acquired." An interesting page is lacking from the rather uninteresting story of post-Darwinian debate as a consequence of the omission on the part of Huxley's opponents to present him with this thesis.

That the little toe is undergoing a real phylogenetic atrophy is a supposition that is supported by a wide series of facts. Not only is the typical human formula $1 > 2 > 3 > 4 > 5$ characteristic of the new-born baby, but it is present in all fœtal stages from that very early time when the digits first make their appearance upon the limb buds. It is a very note-

worthy fact that this peculiar type of foot, which is absolutely distinctive of Homo as a species, should make so early an appearance in the developing embryo. The human embryo does not at any time have its digits arranged upon the primitive formula retained in the monkeys and apes. It does not, more commonly than the adult, possess the so-called Greek ideal

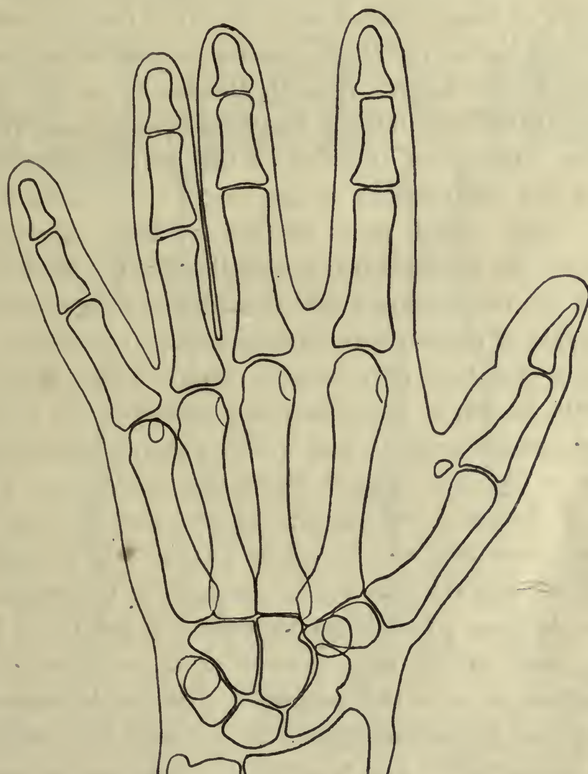

Fig. 16.—Tracing the X-ray of a hand in which the index finger is unusually well developed. The photograph is from the hand of a woman.

foot, with the second toe longer than the first, but it displays very early indeed the typical human diminution of digits from first to fifth.

As for the adult human foot, every one knows what a poor thing the little toe commonly is. Its movements are restricted, its nutrition is generally low, and it is apt to suffer from chilblains. Its nail is frequently ill developed, and not uncom-

monly absent altogether. Very frequently it is bent towards the sole of the foot, and its owner is powerless to straighten it by the aid of its own muscles, and in a large proportion of adults the two terminal bones are completely fused into a single unit, so that it lacks a joint when compared with its next-door neighbours.

It will be seen later on that a great deal of the interest in the anatomy of the deeper structures of the foot depends upon this human distinction of the dominant big toe and the steadily diminishing series of digits towards the fibular side of the foot. We shall see that the human feature of developing the tibial digit at the expense of the rest of the series has produced a shifting of the central axis of the foot as compared with the primitive hand. And from all the evidence available one cannot avoid the conclusion that the digits of the fibular margin of the foot are undergoing a real regression—a regression which is an outcome of human specialisation, and in no sense a result of cramping the toes into modern boots. The little toe is undoubtedly becoming a rudimentary structure; it is entering upon phylogenetic senility, and will end in phylogenetic death.

If then we do not regard the Greek ideal foot, with the second toe elongated in advance of the first, as the typical human foot, how shall we class it as a type? Is it an advance upon the foot with the long big toe, or is it, so to speak, a lower stage in evolution—a less distinctly human type of foot?

Despite what artists may declare as to its greater beauty and perfection, it is to the anatomist a distinctly more animal and less typical human member. It is denied that such a foot ever was the ideal of the Greek sculptors, and it has been asserted that the long second toes seen in Greek works of art are the products of later restorers (Harrison). That it is a common enough type of foot every one knows, and persons who possess such feet are usually not a little proud of the circumstance; but I think that but few artists would admire, and not many people would be proud to possess, that type of foot which stands next to it in order of the failure to attain full human specialisation. This third type is very much more rare, and it is one that cannot fail to attract attention from any one who is at all observant.

In these feet not only is the second toe longer than the first, but the third is longer than the second, the digits being disposed, not in the manner normal to the specialised human foot, but upon the plan of the primitive human hand. In some cases the formula is $3 > 2 > 4 > 1 > 5$, in some $3 > 2 > 1 > 4 > 5$, and in others $3 > 4 > 2 > 1 > 5$. Only the diminutive little toe maintains its characteristic rudimentary form. As a general

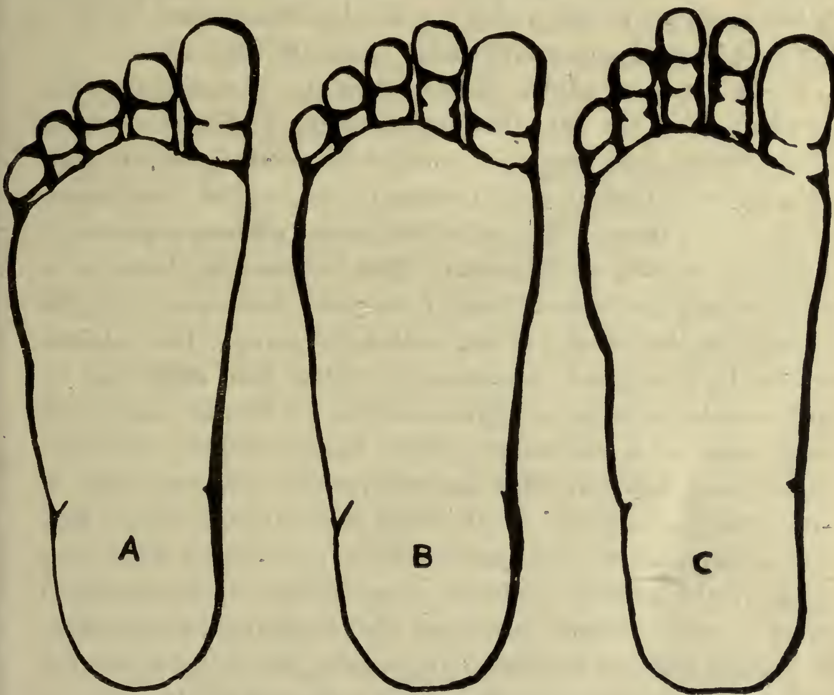

FIG. 17.—Three types of digital formula of the human foot. A, Commonest type. Formula is $1 > 2 > 3 > 4 > 5$. B, The "Greek Ideal" type. Formula is $2 > 1 > 3 > 4 > 5$, or $2 > 1\ 1 = 3 > 4 > 5$. C, Uncommon type (G.E.W. and criminal). Formula is $3 > 2 > 1 > 4 > 5$.

rule, all the digits are unusually long and finger-like, but in some cases the smallness of the big toe is more conspicuous than the actual increase in length of the other digits. This form of foot is distinctly rare; and it may be of interest to followers of Lombroso to know that the case illustrated in Fig. 17, C, is that of a patient who showed some reluctance at having his foot photographed, a consequence probably of the fact, which I learned later, that, though a young man, he had a perfectly astonishing

list of convictions standing to his credit. On the other hand, a similar tracing is taken from the foot of a lady student of blameless reputation. This rare type of foot I regard as the most primitive, most animal, and least human form met with. The so-called Greek ideal stands next, and is not so completely characteristic of Homo as a fully specialised species as is the much more common, and at times rather despised, type in which a long big toe is followed by a steadily diminishing series of digits to a rudimentary and rather shameful little toe.

From a review of the digital formula we may therefore conclude that the human hand presents a picture of basal primitiveness, and that this wonderfully primitive condition is only departed from in some persons by the special development of the index finger. This elongated index we may regard as a distinctly human specialisation. The human foot, however, is an extremely specialised thing; it finds no likeness in its digital formula in the whole existing vertebrate series. It is characterised by the great development of the first digit and by an increasing atrophy of digits towards the fibular side, which culminates in a rudimentary fifth toe, possessing only two phalanges. Moreover, this characteristic occurs very early in embryonic life, and we are therefore justified in believing that it is a very ancient possession of Homo as a species. This is a point of the greatest interest, since, as the specialisation is directed solely towards fashioning a foot capable of supporting an upright body in terrestrial progression, we are led to believe that such a posture is a very ancient attainment of Man.

CHAPTER IV.

The Phalangeal Formula.

We have already seen, in the case of the little toe, that the three phalanges which are normal to its next-door neighbour may undergo an ontogenetic reduction in a large proportion of cases, resulting in the production of a toe which possesses but two free bony elements, and but one joint separating the free elements. Such an ontogenetic change obviously raises the question of possible phylogenetic modifications in the numerical series of the phalanges, and this is a study to which biologists have devoted some attention, since the problem touches upon certain far-reaching propositions. What is the normal number of phalanges which may be considered the birthright of the digitate vertebrate? In discussing the question of pentadactylism we saw that one of the arguments which had been urged in support of the theories of ancestral polydactylism was derived from the examination of limbs which had become converted into aquatic paddles. In this case we concluded that such arguments were misleading, since these paddles were almost certainly specialisations from primitive conditions, and gave no real clue to ancestral plan. In the question of the phalangeal formula we will assume (and here we have even more justification for doing so) that the condition of the paddle, with its multiple phalanges, does not give us a picture of ancestral plan, but rather shows how far this ancestral plan may be modified for purely functional requirements.

Among the Whales (Cetacea) the phalanges may be very numerous, for twelve or thirteen may be present in each digit, and in some extinct vertebrate paddling forms even this number is exceeded; but all the evidence which we possess points to the conclusion that these are examples of functional modifications of a more primitive and more limited formula.

Among the existing digitate vertebrates it is the Reptiles

which show the fullest series of unmodified phalanges, for here the first digit may possess two, the second three, the third four, the fourth five, and fifth four. Such a phalangeal formula may be represented as 2 · 3 · 4 · 5 · 4 · reading from the first to fifth digit. Now, although the other digitate vertebrate groups do not show exactly the same formula, nevertheless all digitate vertebrates agree in being short of one element in the first digit. The thumb and the big toe of the Amphibia, Reptilia, Aves, and Mammals lack at least one element when compared with the more typical digits. What is the element lacking from the thumb and great toe? Has a phalanx become lost, or is the metacarpal of this digit missing in all known vertebrates? This is a question which has been debated ever since the advance of human progress begot that undervalued member of society known as the Anatomist. Galen held that the thumb and great toe consisted of three phalanges, and that the metacarpal and metatarsal were lacking. This opinion has received much support from succeeding generations of anatomists, and with more precise investigations it has gained added confirmation. But one may say that, tempting though the theory may be, it lacks phylogenetic probability. When elements are lost in digits, and when digits themselves are lost in regular evolutionary series, it may be said that the phylogenetic death of the member takes place from the free extremity backwards to the trunk. The metacarpal will persist long after the phalanges are lost, and we need go no further afield than the familiar skeleton of the horse to see in the splint bones the wonderfully persistent metacarpals belonging to digits long since lost in phylogeny.

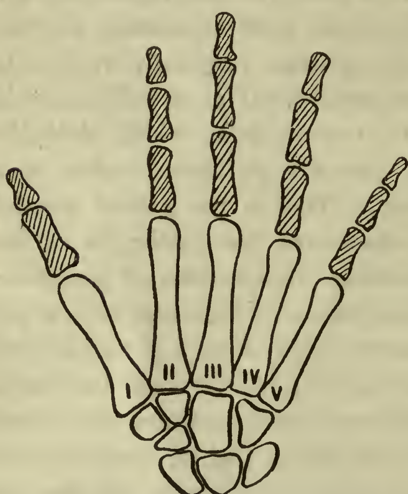

FIG. 18.—The mammalian type of phalangeal formula = 2 . 3 . 3 . 3 . 3.

However, the view that in the thumb and big toe the meta-

carpal and metatarsal are missing, and that the three existing elements are mere phalanges, has many supporters, and the fact that the normal development of the basal bone of the first digit follows the lines of the development of a typical phalanx is evidence which cannot be disregarded. A phalanx is developed from two centres of ossification, the one forming the bone of its shaft, and the other forming an epiphysis for its base, or proximal end. A typical metacarpal or metatarsal is also developed from an ossific centre which forms its shaft, and an added centre which forms an epiphysis, but here the epiphysis is situated at the head, or distal end of the bone, and not at the base. In the case of the proximal bone of the first digit, ossification takes place from a shaft centre and from a basal epiphysial centre in the manner typical of a phalanx.

Upon the evidence derived from the manner of ossification, the majority of anatomists have agreed that the basal element of the first digit is in reality a phalanx, and that the metacarpal bone is absent. Meckel, Rambaud, Renault, Maclise, and Struthers may be mentioned as anatomists who, from a special study of the ossification of this element, have felt convinced that they were dealing with a true phalanx.

Others, however, have not been so satisfied, and they have regarded the basal element as a complex entity which represents both the metacarpal or metatarsal and a phalanx fused together in development.

Uffelmann, Sappey, Poirier, and Windle may be mentioned as supporters of this view, but they do not agree in the exact representation of the different elements in the presumed complex basal bone. Uffelmann maintains that the basal epiphysis of the bone is itself complex, Sappey and Poirier that the basal epiphysis represents the metacarpal, and the shaft represents the phalanx. Windle believes that the basal epiphysis and the shaft represent the metacarpal, and that the distal extremity represents the phalanx. These theories agree only in considering the first element as complex, and that the bone missing as a separate entity is either the metacarpal or the first phalanx, which is represented by a rudimentary structure in the complex bone. Uffelmann's theory, though receiving the

approval of Henle, seems to be supported by very little evidence, and is, on general principles, extremely improbable. Windle's theory does not carry great conviction, even taken in conjunction with the work upon anomalies of the thumb of which it was the outcome. The views of Sappey, which have received the support of Poirier, are undoubtedly those which have the greatest measure of inherent probability, if we are forced to admit that either the metacarpal or the first phalanx is the missing or rudimentary member. But there are many who are not prepared to admit this. It was the early work of Allen Thomson that first provided any ground for believing that the method of ossification of the basal member of the first digit was no safe guide to its homologies. This work has been confirmed and extended by the more recent investigations of Pfitzner. In brief, one may say that a head, or distal, epiphysis may at times be present upon this basal member of the first digit, when its development is, therefore, that of a normal metacarpal; while a basal, or proximal, epiphysis has been observed upon the undoubted metacarpal of the second digit. These facts teach us that we should not rely upon the dictum of Struthers that the position of the epiphysis is decisive in establishing the homologies of the bone. It is possible, therefore, that the basal member of the first digit is a true metacarpal or metatarsal, possessing no added element, but exhibiting an irregularity of ossification which may at times be shared by other metacarpals and metatarsals. When all the factors are taken into consideration this supposition seems to be the most probable, and it is the view advocated here. If then the basal member be assumed to be a metacarpal or metatarsal, the missing member must be a phalanx.

FIG. 19.—The amphibian type of phalangeal formula = 2 . 2 . 3 . 4 . 3.

We have noted that some have pictured the basal phalanx as missing, and have seen its rudiment in the occasional distal epiphysis of the metacarpal (Windle) or in the shaft of the metacarpal (Sappey and Poirier). But this is to admit a complexity of the basal element which does not appear to be justified by facts. Sir John Murray Humphray gave this problem a great deal of attention, and he concluded that the second bone of the first digit was a true first phalanx, and that the second phalanx was the missing member. There is much teratological and anatomical evidence to support this view. Humphray seems to have regarded this second phalanx as being altogether absent; but the more recent work of Pfitzner appears to make it very probable that it has been fused with the third or ungual phalanx to constitute the distal bony element of the first digit. I know no fact derived from any study of normal or abnormal anatomy or from paleontology which contradicts this finding. Moreover, we may study all the stages of the coalescence of the two distal phalanges into a single bony unit in the human little toe, and I imagine that the ontogenetic history of these segments of the little toe tells very truly the phylogenetic story of the two distal segments of the vertebrate thumb and big toe. We will, therefore, assume that the first element of the first digit is the metacarpal or metatarsal, that the second is the true first phalanx, and that the third is a compound element, consisting of the ungual phalanx and the reduced second phalanx, which has become incorporated with it at a period so remote that even " the paleozoic Stegocephali do not possess more than two phalanges " (Howes).

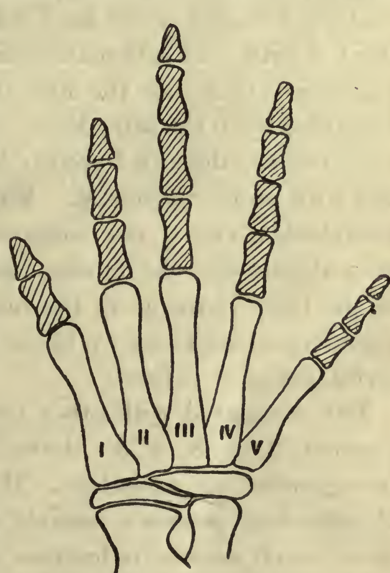

Fig. 20.—A Reptilian type of phalangeal formula = 2 . 3 . 4 . 4 . 3. The full formula is 2 . 3 . 4 . 5 . 4.

Since a first digit possessing but two phalanges is so ancient, and so stereotyped a feature of the digitate vertebrate, it might be asked if great value is to be attached to any of these inquiries as to the precise nature of the missing element. It might be argued that a fuller complement of elements never existed, and that those cases in which added elements are present possess no real phylogenetic significance. Even it might be suggested that, had anatomical thought never passed through a phase in which theories of archetypal uniformity dominated opinion, anatomists might never have imagined that because the second, third, fourth, and fifth mammalian digits generally possess three phalanges, therefore the first digit must have been originally fashioned upon the same lines. Any of these propositions might be extremely difficult to refute if brought forward of set purpose and with proper argument. But here we will not seriously urge unorthodox views, nor support orthodox ones, since for our present purpose the findings are clear enough—the condition of the bony elements of the human thumb and great toe is as primitive as anything we know in the whole digitate vertebrate series, living or extinct.

But, compared with other vertebrate classes, our phalangeal formula 2 . 3 . 3 . 3 . 3 . shows a reduction which can only be regarded as secondary. We have already seen that the Reptiles may possess a formula of 2 . 3 . 4 . 5 . 4 . as a maximum from which various reductions may take place. Obviously, as Professors Howes and Hill have argued, the Mammals and the Reptiles may have sprung from some common and remote ancestral form in which the complete phalangeal formula was 2 . 3 . 4 . 5 . 4 . as a minimum. Were we to follow that type of argument which regards classification schemes as representing phylogenetic routes, we would look to see this ancestral formula realised in the basal stock of the Amphibia. But here this light-hearted method of settling evolutionary progress receives a rude shock, for no amphibian, specialised or primitive, living or extinct, shows a true phalangeal formula more complete than 2 . 2 . 3 . 4 . 3. The reptilian formula is 2 . 3 . 4 . 5 . 4 . or minus by reduction; the mammalian is 2 . 3 . 3 . 3 . 3 . or minus by reduction; the amphibian is 2 . 2 . 3 . 4. 3 . or minus by

reduction. It would seem that the ancestral digitate amniote formula must be 2 . 3 . 4 . 5 . 4 . or plus ; that the mammalian and reptilian formulas could have been derived from the common stem, and that from this common stem the Amphibia have branched off. But it is impossible to picture the Amphibia, with their reduced formula, as being the source of the Mammalian stock. We may therefore conclude that man shows as primitive a phalangeal formula as is seen in any mammal, living or extinct, and that this formula is not derived from any amphibian ancestor, but from a stock common to the mammals and reptiles, from which the amphibia had previously specialised. We have also seen that, whereas Man retains the primitive formula 2 . 3 . 3 . 3 . 3 . for his hand, he is tending towards a specific reduction represented by 2 . 3 . 3 . 3 . 2 . for his foot; and in this case we know that the reduction is attained by the fusion of the two terminal phalanges.

CHAPTER V.

The Metacarpal Formula.

The metacarpal bones are arranged as a series of five long bones which compose the skeleton of the major portion of the palm of the hand. Their heads are conspicuous as the knuckles of the clenched fist when the phalanges are flexed to their utmost at the metacarpo-phalangeal joints; and their bases articulate with the short bones of the carpus. Each of these five bones is possessed of a considerable degree of individuality. They vary characteristically in the degree of mobility which they possess. The basal element of the thumb, which we are here including as a member of the metacarpal series, shows the greatest range of free movement. It can be brought nearer to the side of the index finger when the digits are closed together, and it can be displaced further from the side of the index when the fingers are splayed as widely as possible. It can be removed from the index finger by being pulled directly out from the palm of the hand, and it can be rotated so as to bring its dorsal surface round to the palmar aspect of the hand. Next to the thumb, the little finger shows the greatest degree of mobility in its metacarpal bone, for if its knuckle is grasped it will be found that it can be pulled slightly away from and towards the ring finger and can be moved towards the palmar or dorsal surface of the hand with a fair degree of independence. A similar test will show that the independent movement of the metacarpal of annularis is considerably less than that present in the metacarpal of minimus, and that of the index is still more restricted in its range; while when medius is thus tested it will be found that it is difficult to produce any appreciable movement of the metacarpal bone. As a result of this simple form of examination we learn that the middle metacarpal is the most fixed, that the index metacarpal possesses but little mobility, that annularis shows an increasing freedom of movement, and the greatest

range of mobility is displayed by the marginal metacarpals of the pollex and minimus. This condition of our metacarpal bones is one of the most simple expressions of metacarpal mechanics displayed within the whole range of digitate animals. Two very elementary functions of the hand are subserved by this arrangement, for it permits the five fingers of the pentadactylate manus to be spread apart from the central digit when the fingers are splayed and the palm is broadened ; and it also allows for the advance of the margins of the hand when the palm is hollowed in grasping a rounded object, or made cup-shaped, as when one drinks from the hollow of the hand. The middle metacarpal is the comparatively fixed metacarpal in the primitive condition of the digitate member, and all the features of the bone and, as we shall see later on, of the muscles and nerves are arranged to ensure this fixity of the middle digit. The presence of a large carpal element (os magnum) at the base of the middle metacarpal and the peculiar slotting in of the base by the development of a styloid process are evidences of the bony adaptations for securing fixation for this mid-line member of the metacarpal series.

Only one departure from this most primitive and simple condition of relative metacarpal mobility is seen in the human hand, and this peculiarity we are already prepared to encounter from a study of the digital formula. Our middle metacarpal, which maintains the central axis of the pentadactyle hand, is particularly immobile, and we have every reason to expect that its immediate neighbours, annularis and index, will primitively display an equally lessened degree of mobility. But the very simplest test will convince us that the mobility of the index metacarpal is far less than that which can be evoked in the metacarpal of the ring finger. Here again we come upon a specialisation of the human index finger—a specialisation which consists in an unusual degree of stability of its metacarpal bone. We have only to turn to the bone itself and notice the peculiarity of its articulation with its carpal bone (trapezoid) to understand why this metacarpal element possesses so limited a degree of independent movement. Although one would not wish to add a jot to knowledge of unnecessary details demanded of the

student by the examiner, it might be pointed out that a glance at the peculiar notched base of the index metacarpal serves to distinguish this bone from any other member of the series with absolute certainty (see Fig. 22).

Turning to the skeleton of the foot, the study of the pedal digital formula has already prepared us for meeting with some departure from the primitive condition of the metatarsals. The primitive mid-line of our pentadactyle hands is evinced in our stable middle finger, and the only departure from this simple condition is the relative fixation of our index metacarpal. In the foot, however, we have seen that there is a shifting of the digital dominance towards the big toe, and that the fifth digit is undergoing atrophy. With this peculiarly human change the mid-line of the foot is shifting towards the dominant big toe, and, instead of the middle toe being slotted into the tarsus and rendered stable, it is the second toe which takes on this *rôle* and which is dovetailed into the tarsal elements. Our second toe has become the fixed point from which and to which the other toes are moved. The fixed mid-line of the foot has shifted towards the elongated first digit, and the evidence derived from the study of the bones is confirmed by the evidence derived from the study of the muscles.

When we turn to the relative lengths of the metacarpal bones we are faced with very much the same problem as that which confronted us in dealing with the relative lengths of the fingers, and again we can express the different conditions met with as a numerical formula. This metacarpal formula finds its primitive plan as $3 > 2 = 4 > 5 = 1$, where the numbers represent the metacarpal bones from first to fifth, and the order signifies the degree of forward projection of the head of the bone when the hand is maintained in the axis of the forearm. The primitive metacarpal formula, therefore, takes the same form as that which we have seen in the case of the digital formula ; in other words, the metacarpal length is proportionate to the total finger length in the primitive manus, and the formula in either case is $3 > 2 = 4 > 5 = 1$.

As an example of this generalised condition the beautiful little hands of *Tarsius spectrum* may be instanced, for the per-

fect radiating symmetry of the metacarpus of this curious little Primate is very striking. In *Tarsius* a primitive metacarpal formula is combined with an almost perfectly primitive digital formula; but in animals which have modified hands a primitive metacarpal formula may be found in combination with variously specialised digital formulæ. In Man the primitive metacarpal formula of *Tarsius* is commonly met with, and all that is necessary to ascertain this fact is to examine the knuckles of the clenched fist and see which knuckle projects the furthest. In some people the knuckle of the middle finger projects ahead of the others, and the knuckles on either side of it fall equally short of it (see Fig. 21, A). In other people it will be seen

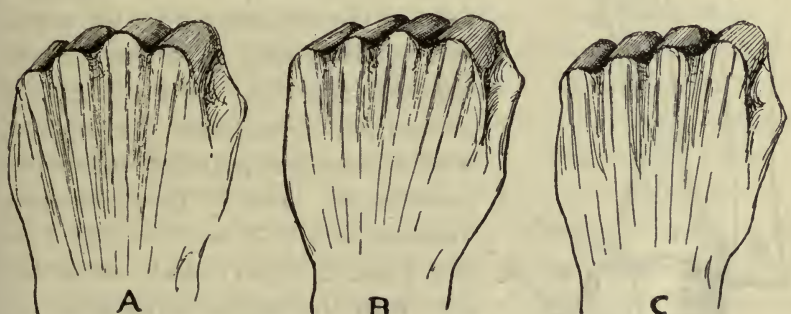

Fig. 21.—Three types of metacarpal formula. In A the formula is $3 > 2 = 4 > 5 > 1$, in B $3 > 2 > 4 > 5 > 1$, and in C $2 > 3 > 4 > 5 > 1$.

that, although the middle knuckle is in advance of all the others, the knuckle of the index finger projects further than does the knuckle of annularis (see Fig. 21, B). In this case the formula would be expressed as $3 > 2 > 4 > 5 > 1$. But in what is probably the commonest type of hand the index knuckle is in advance of all the others, and the formula then is $2 > 3 > 4 > 5 > 1$ (see Fig. 21, C). Now the curious fact is that this elongation of the index metacarpal is not necessarily associated with the elongation of the index finger as a whole. The metacarpal formula may be $2 > 3 > 4 > 5 > 1$, while the digital formula is $3 > 4 > 2 > 5 > 1$. Neither is the primitive relative shortening of the index metacarpal expressed by the formula $3 > 2 = 4 > 5 > 1$ necessarily associated with a shortened index finger. On a metacarpus of the most primitive formula one may find

fingers arranged in the manner which is so peculiarly human, and which may be expressed by the digital formula $3 > 2 > 4 > 5 > 1$.

Although the elongation of the index finger is a human peculiarity, the elongation of the index metacarpal is a distinctly simian feature, for the typical monkey metacarpal formula is $2 > 3 > 4 > 5 > 1$.

In the Anthropoids some variation is seen. The Gibbons have a very elongated index metacarpal, but the Chimpanzee occasionally shows index and medius of the same length, while the Orang commonly possesses a primitive long middle metacarpal. Among the Lemurs the departure from the primitive condition seen in *Tarsius* is in the opposite direction, for in them the metacarpal of annularis is elongated, while the metacarpal of index remains primitively short. The Lemurine formula is $3 = 4 > 2 > 5 > 1$ or $3 > 4 > 2 > 5 > 1$; and, as is the case with the digital formula, it expresses the specialisation of the fourth digit at the expense of the second.

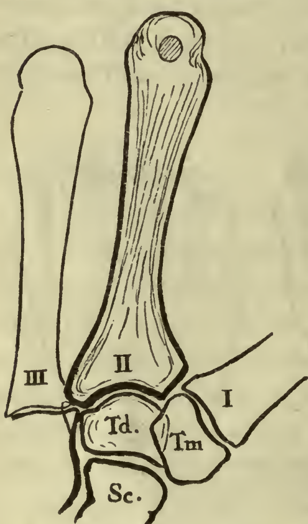

Fig. 22.—The carpal articulation of the base of the metacarpal of the index finger. Td = Trapezoid. Tm = Trapezium. Sc = Scaphoid.

Here again we come upon a story very like that which we have read before, for from an examination of the metacarpal formula we find the primitive condition constantly in *Tarsius*, and commonly in Man. We find a definite simian type as a departure from the primitive condition, and this type we find also as a variant in Man. And, still within the limits of the Primates, as this order is usually defined, we find a definite lemurine formula which is a departure from the primitive condition on lines altogether distinct from the simian modification.

One other point must be noted in connection with the human condition of the metacarpal bones. In the primitive metacarpus the middle metacarpal is not only the longest bone in the series,

but is also the most stoutly built and massive member of the metacarpus. In the monkeys, although the metacarpal of the index exceeds the middle metacarpal in length, it falls short of it in bulk. But in Man the metacarpal of the index is commonly an extremely stout bone, exceeding the middle metacarpal in bulk, even if it falls short of it in length. There would appear to be but little doubt as to the functional meaning of this structural change, since the increase of the index metacarpal is definitely related to the use of the index finger as a companion to the mobile thumb in the act of picking up objects and grasping them between finger and thumb. The specialised preaxial thumb begets a specialised metacarpal in its opposing index finger; and we might predict, with a fair certainty of success, that any animal which has the power of using the thumb and index finger in the forceps action of taking objects between these digits will show a specialisation of the index metacarpal. And we may note that if no more than this forceps action is demanded of the index finger, then the metacarpal specialisation need not lead to an alteration of the digital formula by a lengthening of the entire index digit. Indeed, the common condition in the monkeys is that, although the index metacarpal is increased, the index digit is relatively reduced. Some other factor must be involved in the human specialisation which leads to the development of an elongated index finger on a sometimes short, but always stout and specialised, index metacarpal.

CHAPTER VI.

The Carpal Formula.

The carpus consists of a series of small bones wedged together as little blocks composing the skeleton of the base of the palm of the hand and the wrist. On the one side these little blocks of bone articulate with the bases of the metacarpal bones at the carpo-metacarpal joints, and on the other they meet the lower articular surface of the radius at the radio-carpal joint. They are arranged in two rows, a proximal and a distal row, with a mid-carpal articulation running between the two rows. In the normal human carpus there are eight small bones, the description of which, and the methods for determining their identity, and the side to which they belong occupy a lamentably large part in the education of the medical student. The author regards it as one of the defects of present-day medical education that the student may occupy a period of fifteen months with good and honest work acquiring as sound a knowledge of the general structure of the human body as can reasonably be gained in that short time, and at the end of this apprenticeship meet an examiner who tests this knowledge in twenty minutes spent in haggling about the details of a carpal bone. Here we will avoid probing into any minutiæ which could possibly arm an examiner with another trivial but deadly weapon. These carpal bones went unnamed until Michael Lyser wrote his "Culter Anatomicum" in 1653. Before that time they were simply distinguished by their numerical position in the carpal series. Many anatomists have regarded Lyser as a fool for his pains, but since the older numerical method suffered from the defect that there was no universal agreement as to which was to be reckoned the first, and which the last, in the series, we can only agree that his work was a useful one. Did we have any doubt as to its utility, it would be readily dispelled by a study of any recent text-book in which use is made of the non-

Lyserian terminology which passes under the title of the Basle Nomina Anatomica (B.N.A.). None of these B.N.A. terms will be used here, but it is only fair to add that, although most of us who do not adopt this terminology believe that in retaining the older nomenclature we are using the names of the carpal bones in exactly the way in which Lyser defined them, we are, as a matter of fact, still perpetuating an error in terminology made originally by an Edinburgh anatomist. Since the point is one of interest, it is worth while to quote Lyser's description of the carpus in the "Culter" (Liber V., cap. 11, p. 173):—

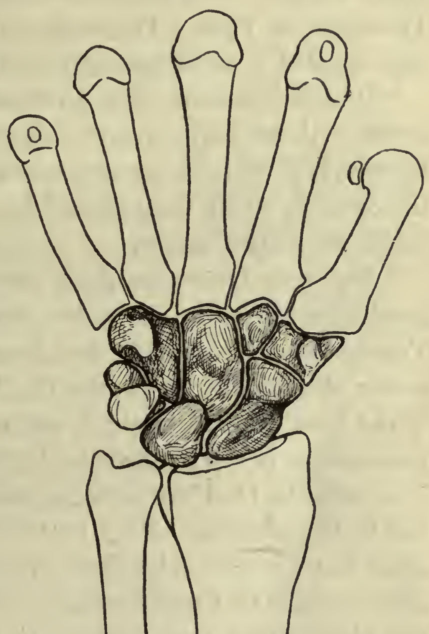

Fig. 23.—The normal human carpus from the palmar aspect. The position of the bones is taken direct from an X-ray, and does not accord in all details with figures drawn from articulated specimens.

"Impossibile enim est oratione cum manifestare cum propriis nominibus ossa ista carent. Tentabo tamen an aliquali descriptione, quo ordine conjugenda sint, indicare possim, impositis nominibus à forma eorum depromptis. *Pollici subjacet cubiformi simile, sed valdè inæqualibus lateribus; trapezoides rectius diceres: Indici trapezium:* Medius pro fundamento habet os omnium in carpo maximum et crassissimum, in posticâ parte capitulum obtinens: Annulari et minimo substat os unciforme, quia interius in manu unci in modum est incurvatum, huic adjacet in latere externo aliud ossiculum, cujus latera quatuor triangula conficiunt, cuneiforme dici posset; cui iterum adhæret minus adhuc ossiculum pisi sativi magnitudine, parte ea, quæ priori objicitur, depressum. Sex illa ossa ordine recensito connectenda. Ideoque singula bis acu pertundes, ac filum sicuti per summa metacarpi capita traduces; non tamen in

recta linea conjunguntur, sed obliquè nonnihil et ascuatim. Bina adhuc supersunt ossa, quorum alterum κατμλοειδες appello, obsinum, quo capitulum maximi ossis recipit: alterum lunatum nomino, quia sinum nactum est semilunarem, quo eidem capitulo occurrit."

After an interval of nearly a century the work of Lyser was translated, and, under the title of "The Art of Dissecting the Human Body," was made familiar to English readers by George Thomson in 1740. Thomson's rendering of the passage we have quoted is as follows (pp. 253, 254):—

"It is not possible here to direct you by verbal instruction, because those bones have no proper names affixed to them. However, I will, in some measure, endeavour to account for the order in which they should be joined by giving them names taken from their figure.

"*Under the thumb lies the os cubiforme, which, on account of the great irregularity of its sides, should rather be denominated Os Trapezoides. Under the fore-finger is placed the Trapezium,* under the middle finger the Os Magnum, so called because it is the greatest and thickest one in the Carpus, having a small prominence in the hind part. Under the Ring and Little fingers is situate the Os Unciforme, so called from being crooked in the inside like a hook. Next to this, on the outside, lies another small bone, whose sides make three small triangles, and may be denominated Os Cuneiforme; to it is joined a small bone, about the bigness of a Pea, concave on that side which lies next the former. These six bones must be joined in the order now mentioned, and each of them twice perforated with a needle; then draw the wire, as above directed, through the superior heads of the metacarpal bones, but they must be placed a little oblique and crooked. Two bones are yet remaining, one whereof I call κατμλοειδες, because of its sinus, which receives the small head of the Os Magnum, the other the Os Lunatum, because it has a sinus in form of a half-moon, which receives a part of the same protuberance of the Os Magnum."

But meanwhile the Lyserian names had found their way into current anatomical literature. Alexander Monro (primus) had published his very successful little work on the "Anatomy

of the Bones " in 1726. In this work Lyser is quoted as the authority for the nomenclature, but a curious change is introduced. Describing the distal row of carpal bones, Monro says (p. 271): " *The Trapezium is the first of the second row, and is situated betwixt the Scaphoides and the first joint of the thumb; the Trapezoides is immediately on the outside of the Trapezium;* the Os Magnum is still more external; the Unciforme is farthest to the side of the Little Finger." George Thomson himself wrote a work on the " Anatomy of the Human Bones " in 1734, and he also used the term Os Trapezium for the bone lying beneath the thumb, and Os Trapezoides for that beneath the index finger. Since that time this alteration in the order of application of the nomenclature of Lyserus has remained permanent, and when we speak here of the trapezium we mean that bone which lies beneath the first metacarpal, and which Lyser named the trapezoid, and not the bone which lies beneath the metacarpal of the index to which he originally gave the name trapezium.

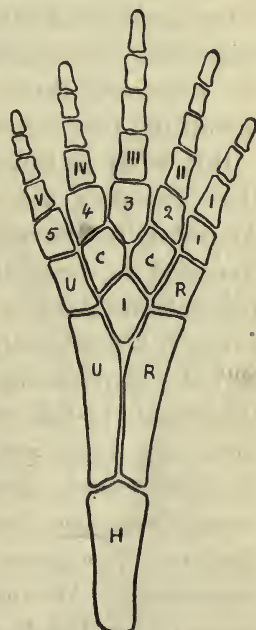

Fig. 24.—The ideal carpus (modified from Gegenbaur). U = Ulnare. R = Radiale. C = Centrale. I = Intermedium.

So much for the names of the carpal bones. As to their primitive number and the plan upon which they are arranged there is much difference of opinion.

Human anatomists have always described the carpus as consisting of two rows of bones, a row next the fingers and a row next the bones of the forearm; but as to the precise constitution of these rows there has not always been agreement. It will be noted that Lyser described a distal row consisting of six bones: the trapezoid, trapezium, os magnum, unciform, cuneiform, and pisiform, being arranged in linear series from radial to ulnar side. Lyser was writing from the point of view of the practical anatomist, and was laying down directions for properly articulating the carpal bones in the skeleton. He

strung these six bones in a row by running a wire through the series. In his second row, which he drilled for a separate wire, were the scaphoid and the semilunar only. The modern anatomist has a different plan for arranging the rows of carpal bones, but it is of interest to notice that the practical articulator is still true to the teaching of Lyser, for he commonly strings the six bones in one row, just as Lyser directed nearly three centuries ago. Nowadays the distal row of the human carpus is universally described as consisting of four bones: trapezium, trapezoid, os magnum, and unciform, and the proximal row of the remaining three: scaphoid, semilunar, cuneiform, with the doubtfully true carpal element the pisiform.

But we know from a study of the fore limbs of other animals that this does not represent the most primitive basal plan. According to Pfitzner's most recent work, the primitive carpus consisted of some thirty-three bones, arranged in five rows. His antibrachial row contained two bones, the proximal carpal row six, the intercarpal row eight, the distal carpal row five, and the carpo-metacarpal row twelve. Previous reference has been made to this work in dealing with the question of supernumerary digits, and although it must be admitted that this idealised carpus gives us a complete picture of the range of human variation, and possibly of the variety of human carpal fractures, it appears to be of extremely doubtful phylogenetic importance. We may admire it as a composite view of known anomalies without admitting that it represents any stage in evolution or believing that any animal ever possessed such a carpus. On the other hand, we have a very definite knowledge of the carpus as it actually exists in an extremely primitive condition, and from a study of the most elemental forms of the carpus it is by no means impossible to deduce an ideal condition for the pentadactyle, or primitive, limb. Such an ideal has been most successfully propounded by Carl Gegenbaur ("Vergleichende Anatomie der Wirbelthiere," 1898, Vol. I., p. 520), and it is a far more simple affair than that derived from a study of human anomalies. No more than nine, or at the most ten, bones go to the make-up of this conception of the primitive carpus, and it is a very remarkable thing that the human con-

dition shows only comparatively minor departures from the ideal. But already we are prepared for this, since we have seen that in other respects the human hand is modelled upon remarkably primitive lines.

This ideal carpus is most easily understood by reference to Gegenbaur's original diagram (*op. cit.*, Fig. 330), which is redrawn here as Fig. 24.

It is somewhat difficult to describe this primitive carpus in definite transverse rows, since the different bones tend to be placed in radiating lines leading from the axis of the limb towards the different digits. There is, however, a definite distal transverse series of five bones—the carpalia—arranged one at the base of each of the five metacarpals. These carpalia are numbered, like the digits, from 1 to 5, from preaxial (thumb) margin to postaxial (little finger) margin. Thus at the base of the first metacarpal is the first carpale, and so on. Behind these there is a series of three, or perhaps four, bones—one on the preaxial border, next the radius: radiale; one on the postaxial border, next the ulna: ulnare; and one or two in the centre, between radiale and ulnare: the centralia. The radiale articulates with the radius, and the ulnare with the ulna; but the centralia fall in the gap between the two forearm bones, and articulate with the single remaining carpal element, the intermedium, which occupies this gap. The presence of two centralia need not be taken into great consideration, for very early in phylogeny a single bone—the os centrale—is found in the midst of the carpus; and only one living reptile (the aberrant Sphenodon) shows the presence of two definite centralia, and this only in its earlier stages of development. According to Baur, a double centrale is never present in any Mammalian embryo, with the doubtful exception of *Centetes*.

FIG. 25.—The ideal carpus as it is realised in a water tortoise (*Chelydra serpentaria*). (After Gegenbaur.)

The first modification of the ideal carpus is one that is

evidently very early established in the phylogeny of the digitate vertebrates, for it is found in Amphibia and Reptiles as well as in Mammals. Instead of five separate carpalia being present, one at the base of each metacarpal, only four separate bones exist, and of these four the one upon the ulnar side articulates with the two metacarpals of the fourth and fifth digits. There is no mammal which does not show this numerical reduction of the carpalia from five to four by the fusion of the fourth and fifth bones into a single element. The four carpalia which constitute the distal row of the typical mammalian carpus are named in human anatomy trapezium, trapezoid, magnum, and unciform, the unciform being the compound bone into the formation of which the primitive carpalia 4 and 5 enter.

Fig. 26.—The carpus of a rabbit. Dorsal view of a naturally articulated specimen.

The fact that the two ulnar-sided carpalia fuse into an unciform bone in all mammals, as well as in some reptiles and amphibians, leads us to suppose that some deep-seated factor which is common to all three classes must account for the condition. Such a supposition is made the more likely when we consider that an exactly similar change takes place in the foot, where fusion of tarsale 4 and 5 leads to the formation of the cuboid bone. In those early days of the evolution of digitate vertebrates somewhere back in the Triassic, when the increasing bodily activity of the animal demanded the development of limbs which not only helped to propel the body forwards, but also to lift the body sheer off the ground, many and far-reaching changes took place in animal structure. The early clambering efforts of such an animal opened the way to many possibilities, and, among other things, they were capable of development into true arboreal climbing, or into highly specialised cursorial fleetness of foot. When the pentadactyle vertebrate first began to clamber and to climb, two changes took place in hand and foot. The preaxial digits were specialised for grasping and for suspending the body weight in climbing; the postaxial digits were specialised for pressing backwards and downwards

as the animal progressed forwards. When the primitive pentadactyle limb came into action the preaxial border advanced as the limb was swung upwards and forwards ; then the preaxial digits obtained a grasping hold and maintained it as the body advanced over the limb ; next, the postaxial digits were pressed downwards and backwards, a " push-off " from the postaxial margin was obtained, and the limb repeated its cycle of action again. In the need of strength and solidity in the postaxial margin of manus and pes, demanded by this action of pushing off and sustaining the body weight, we probably find the clue to the fusion of elements which has led to the production of the unciform and cuboid. With the fact of fusion of the two elements we must also correlate the very early ossification of the compound bone, which is another physiological expression of the need for stability in the postaxial margin of manus and pes. By the time the mammals came into being fusion of the two postaxial elements had already become a vertebrate birthright, and so, although the human carpus shows this as a departure from the most primitive condition, the departure is a very early one indeed, and no mammal can boast of a more primitive numerical condition of the carpalia than that seen in the human carpus.

The changes in, and the fate of, the other elements of the carpus are not quite so simple.

The primitive ulnare is represented by the human cuneiform, and the primitive radiale is certainly incorporated in the scaphoid. The fate of the primitive intermedium is open to more debate, but here we will adopt the view, which is very generally held, and for which there is much evidence, that it is represented in the human semilunar.

Only one bone of the primitive carpus is therefore lacking as an individual entity in the human carpus. This lost element is the os centrale. Around this question of the fate of the os centrale a very abundant literature has grown up, and the question is one of some importance in human phylogeny. A cartilaginous nucleus for this bone appears in the embryonic human carpus, but in later stages of development no separate cartilage is to be found. What has become of it ? It has

been said to disappear altogether by a process of retrograde development. It has been said to degenerate and to be represented in the adult carpus as an inconsiderable ligament which passes between the os magnum and the scaphoid. It has been described as merging into the growing cartilages of neighbouring bones, and so becoming incorporated into the mass of the adult os magnum or the adult scaphoid. In such a question as this phylogeny, or the evolutionary story of the species, as well as ontogeny, or the development of the individual, must be taken into account. The following of the fate of a bony element through a series of animal forms may be a clear and simple business compared with keeping the track of a minute cartilaginous mass through a series of stages of development in the individual. Such would appear to be the case with the os centrale. Human embryologists, from the examination of sections of the carpus of successive stages of human development, have arrived at very different conclusions as to the fate of this minute cartilaginous nodule. But when the os centrale is examined—and especially by X-rays—in a series of mammalian types there would seem to be but little doubt as to its situation in the human carpus. In the first place, although the os centrale is truly a central carpal bone in generalised reptiles and in some mammals, it tends to move towards the preaxial (radial) border of the carpus in many forms. This preaxial migration is especially well seen in the Primate Series. In *Tarsius spectrum* the centrale is a separate bone, and is still in a sufficiently central position to enable it to articulate with the intermedium (semi-

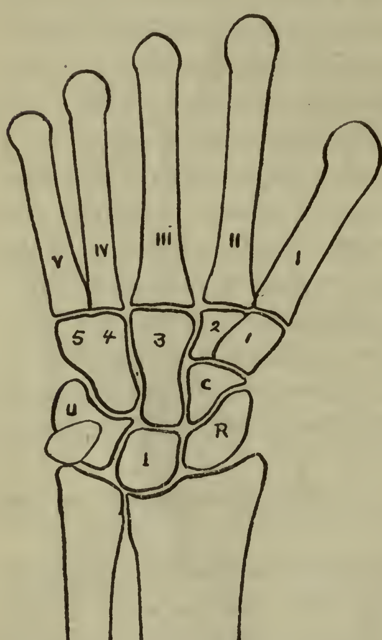

FIG. 27.—The carpus of a Rhesus monkey, from an X-ray.

lunar) as well as with the radiale (scaphoid) on its proximal margin, while on its distal margin it articulates with os magnum, trapezoid, and trapezium. In the monkeys, however, it may not extend sufficiently far towards the centre of the carpus to meet the semilunar, the whole of its proximal articular surface being taken up with the scaphoid. In this condition the os centrale articulates at its distal end with the trapezoid and trapezium, at its ulnar or central margin with the os magnum, at its proximal margin with the scaphoid, and a small portion of its radial margin may be non-articular and appear at the free radial border of the carpus (see Fig. 27). This is the condition which is usual in monkeys, and which is present in the orang utan among the anthropoid apes. This change in the position of the os centrale would seem to be determined, in part at least, by the great development of the os magnum. Just as the unciform was developed as a solid block of bone from the fourth and fifth carpalia to afford support for the digits on the " pushing off " postaxial margin of the manus, so carpale 3 becomes specialised as a firm block of bone for the support of the important and fixed middle line digit. The dominant size of the os magnum may be regarded as a symptom of the fixity of the third digit. Meanwhile but little stability is required for the preaxial digits. The index finger is small in the lower Primates, and the thumb is weak ; but they are possessed of much mobility, and four independent little blocks of bone lie between their metacarpals and the radius. In Man, however, the thumb is large, and in Man and, in a lesser extent, in the Gorilla and Chimpanzee the index finger has become an important and specialised digit. In these three types there is a change in the carpus. The trapezium and trapezoid continue to be separate elements, but at their base they articulate with a single large bone—the human scaphoid. The centrale has disappeared as a separate entity, but its fate in phylogeny appears to be perfectly clear, for its site in the simian carpus is exactly occupied by the very distinct distal portion of the human scaphoid. A study of comparative anatomy therefore gives irresistible support to the embryological finding that the human scaphoid is a compound bone, being composed of the primitive scaphoid

in its proximal part and the preaxially displaced os centrale in its distal part. And, from a functional point of view, we may regard this as another expression of the specialisation of the functions of the human index finger, a specialisation which finds some mimicry in the two African anthropoid apes.

We therefore find from a study of the human carpus that it is in an extremely primitive condition; it is, in fact, far more like the carpus of a water tortoise than are the carpuses of the generality of "lower mammals," in which far greater fusions and numerical reductions have taken place. But nevertheless it is not so primitive a carpus as is that of *Tarsius spectrum* and the monkeys, for the independence of the os centrale has been lost by fusion with the radiale; and this we imagine to be a physiological expression of a need for stability at the base of the important index finger. The ossification of the carpus and tarsus would be far more interesting to the student were the functional value of the different elements and their phylogenetic story kept in view. We have pictured the fixity of the middle line digit of the pentadactyle manus as being an extremely primitive feature, its carpal element enlarges (and perhaps absorbs one of the two primitive centralia) to afford it adequate support at a very early date, and it is the first bone on the carpus to ossify. The aggregation of carpalia into the unciform to afford support for the "pushing off" postaxial digits comes next in our imagined phylogeny, and the unciform ossifies next in order and lags only very slightly behind the os magnum. The formation of a large and compound bone mass at the base of the index, we imagine, is a recent acquirement, and the scaphoid, although such a large mass, is the last of all the carpal bones to ossify.

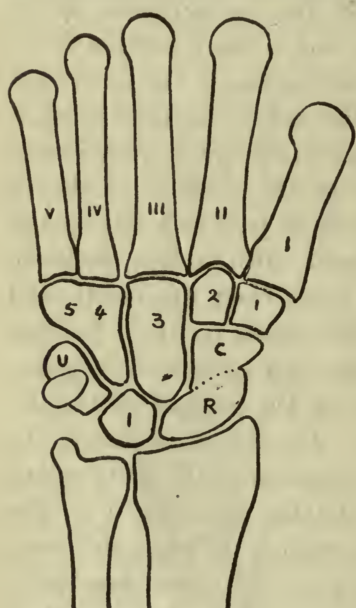

Fig. 28.—The human carpus, from an X-ray.

CHAPTER VII.

The Flexure Lines.

The lines which mark the palm of the hand and the sole of the foot consist of two entirely distinct elements, and, roughly, we may say that the coarser and more conspicuous lines are flexure lines, while the finer markings are made up of the papillary ridges. Both sets of lines have provided material for detailed studies. The flexure lines of the hand are those which chirognostics, and persons who read characters and tell fortunes, examine critically in the exercise of their calling. The papillary lines are the palmar markings to which even more minute attention is given by those responsible for the detection, registration, and identification of criminals. The flexure lines of the foot do not appeal to the professional fortune-teller, nor do the papillary ridges upon the sole receive much study from the criminologist, but both sets of lines upon both sole and palm have a well-defined place in the literature of anthropology. And, indeed, apart from the identification of the criminal, and apart from the lore of the palmist, these lines illustrate vital principles and are worthy of all, and more than all, the study that has been devoted to them.

Since flexure lines and papillary lines are utterly different things, we will separate them sharply from one another; and, in the first place, attention will be paid to the more conspicuous lines upon which the palmist has lavished so much professional attention.

We may quote from an authoritative "Manual of the Science of Chiromancy" a passage which shows the way in which the palmist regards these creases: "In every hand there are lines of certain depth, colour, and length, and according to their accentuation, so will the qualities they indicate be more or less present in the individual. We do not say that these qualities will be evident to the ordinary observer, nor even

that they are observable at all. They exist in his or her nature, but may be kept in subjection and self-denial by religious training and force of character—in a word, by other lines." It is not in this subtle way that we shall regard these lines, for we are concerned solely with the creases as anatomical structures having definite relations to physiological functions.

Flexure lines, no matter where they are met with upon the surface of the body, are of importance and of interest, for they are the surface registration of the mobility of parts. Wherever they are found their significance is the same, for they always indicate the folding point of the skin and subcutaneous tissues. They mark the site of what may be termed the skin joint, brought into action by the movement of an underlying bony joint. But they do not always, or even generally, mark upon the surface the exact position of the underlying bony joint, for the joint is separated from the surface by a varying thickness of intervening tissues. The point of skin movement may be translated some distance from the point of joint movement by the intervention of various tissues. The flexure lines upon well-worn boots or garments do not mark accurately the site of the crease lines upon the skin, for the resistance of the intervening layers of socks and shirts has to be reckoned with. In like manner the flexure lines upon the skin may not mark the line of the joint, since various layers of muscles, ligaments, etc., may be interposed between the moving bones and the yielding skin. At times this simple fact is lost sight of, and even those responsible for the treatment of the disordered bodies of their fellows are apt to picture joints as lying accurately below skin creases (see Fig. 37).

The outstanding feature of all flexure lines is that they constitute points of comparative skin rest. Evidently at these lines there is some anchoring mechanism fixing skin to deeper tissues, and allowing a constant creasing of the skin at one fixed line. They are more than mere folds, like the creases upon the bend of the elbow of a well-worn coat sleeve, for, to make the parallel a true one, the crease on the coat would have to be bound down to the crease on the shirt, and this again to the crease on the vest. The crease lines of the skin are comparatively fixed

and permanent; those of the coat may change from day to day. It is this binding down of the skin—the fixing of the line of rest—that constitutes one of the most important features of flexure lines from a practical point of view. This fact may be instanced by turning to quite another part of the body, and studying the lines upon the skin over the lower portion of the abdomen and upper portion of the thigh. In every subject the line of division between the musculature of the abdomen and the thigh, which is marked by Poupart's ligament, is apparent as a depressed area running from the anterior superior spine of the hip bone towards the symphysis pubis. In a muscular male subject this intermuscular depression becomes particularly evident, and no figure of an athlete, or model of a Hercules, will fail to show this deep oblique gutter separating abdomen from thigh. This line is merely an evidence of the muscular modelling of the body. But in subjects in which there is a fair development of subcutaneous fat in this region—and this is far more common in women than in men—another line becomes apparent upon slight flexure of the thigh at the hip joint. This line starts in the region of the symphysis, in common with Poupart's line, but when traced outwards on to the thigh it falls steadily below Poupart's line, and comes to an end over an area, which is always marked in a well-formed figure as a depression, and which indicates the site of the great trochanter of the femur. The great trochanter can always be easily felt as a hard lump of bone unclothed by muscle, and upon this hard depressed

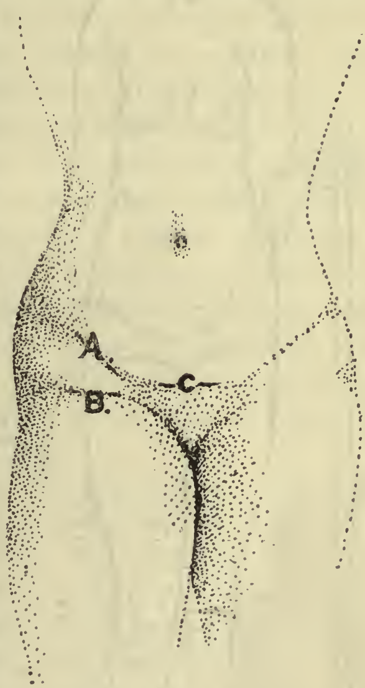

Fig. 29.—The lines of the groin of a woman standing with the right hip very slightly flexed. A, Poupart's line. B, Holden's line. C, Line of Venus, or Sillon pubo-hypogastrique.

area upon the outer side of the thigh this second, lower, line becomes lost. In its general trend this line may be said to run almost parallel to the ground, and so, towards the outer side of the thigh, it falls considerably short of Poupart's line, which runs upwards as it is traced outwards (Fig. 29). This line is sometimes called Holden's line, since Luther Holden drew attention to it in his little book on "Landmarks, Medical and Surgical" (1876), and he noted the importance of the circumstance that in passing over the top of the great trochanter of the femur it marked the line of the hip joint. It is in fact the flexure line of the hip joint. But, naturally enough, many were familiar with this line long before Holden pointed out its relation to the hip joint. One has only to look at the drawings of old masters to see how well they were acquainted with this flexure line, and it is rather curious that Albert Durer gave quite a sexual value to it, since he invariably depicts it in female figures and omits it in the male (Fig. 30). It is, indeed, far more conspicuous in the female and in the young child than it is in the adult male,

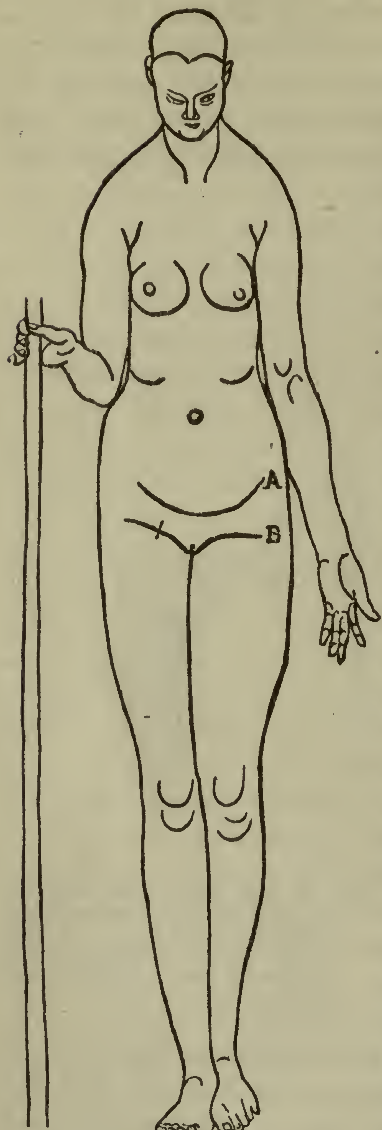

FIG. 30.—Drawing of a female figure by Albert Durer. A, Poupart's line. B, Holden's line. (From "Della Simmetria de i corpi humani," 1591.)

and this is so for the reason that the presence of fat in the upper part of the thigh accentuates its presence. The formation of

this line is of interest. Beneath the skin lies a bed of fibrous tissue in which the subcutaneous fat is emeshed in those parts of the body where fat is present. This bed of tissue is known as the superficial fascia. Beneath the superficial fascia lie the muscles and deeper structures of the body, and these are surrounded by their own denser fibrous tissue bed, which is known as the deep fascia. Between the skin and the superficial fascia and the deep fascia a considerable mobility is permitted. The skin may be pulled up in folds and slid about upon the underlying muscles. But this degree of mobility does not exist in all parts of the body. At flexure lines the superficial fascia and deep fascia are blended, and the skin becomes more or less anchored to the deeper tissues. This blending is present at Holden's line, and it is for this reason, and for nothing more mysterious, that fluids, such as urine, extravasated between the deep and superficial fascias of the abdominal wall, will not pass down into the thigh. Their passage is barred at the flexure crease, where the layers are blended at the rest line of the skin over the hip joint.

There is another lesson of universal application in the body which may be learned from a study of the relation of skin and fascia at the crease line of the thigh. The crease line is accentuated by the presence of subcutaneous fat. The subcutaneous fat is enmeshed in the fibrous strands of the superficial fascia, and the disposition of the fibrous tissue depends upon the amount of fat enmeshed within it. Where little or no fat exists, the superficial fascia appears as a simple, loosely felted membrane lying immediately beneath the skin. Where only a moderate amount of fat is present, it is held in loculi of fibrous tissue, as we might picture a thin slice of sponge impregnated with fat. But where the fat is abundant, the fibrous tissue in which it is held becomes more dense upon both superficial and deep surfaces of the fat pad, and now one may detect a superficial fibrous layer, a sponge-work pad of fat, and a deep fibrous layer. The enmeshed fat becomes enclosed in a capsule of thin fibrous tissue. This is the well-known condition of the fat and gland tissue in the mammary gland. The same condition is present in the lower portion of the abdominal wall in persons who have a

well-marked layer of adipose tissue, and here the superficial fibrous layer and the deeper fibrous layer have, rather unneces-

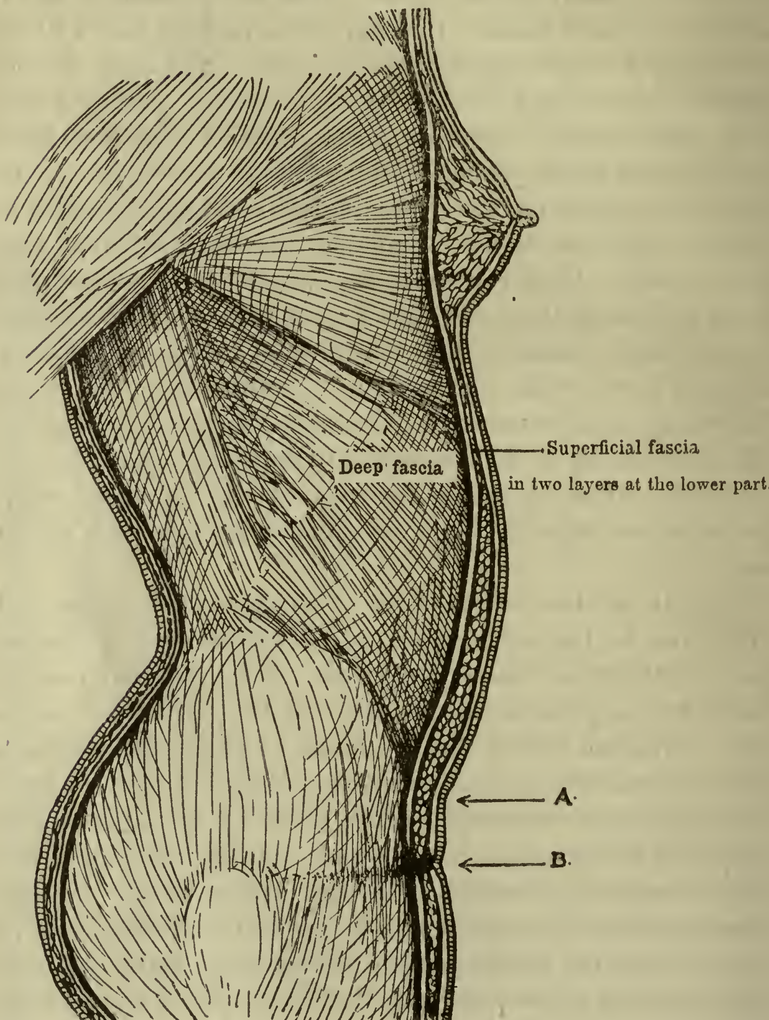

FIG. 31.—Diagrammatic view of the body with the surface layers cut in section along a line passing vertically down through the nipple and the mid-point of Poupart's ligament. A, Poupart's line. B, Holden's line.

sarily, received special names. The front layer is known as Camper's fascia, and the back as Scarpa's fascia, and this, not unnaturally, causes considerable confusion for the student

of human anatomy. But this confusing state of affairs comes to an end at the crease line of the hip, for here the fascia of Scarpa must be bound down to the deep fascia, and the pad of fat must be constricted by fibrous tissue joining the back and front layers of the fat sandwich. In this way the line of skin rest at Holden's crease is attained.

A simple diagram (see Fig. 31) makes the arrangement more clear, and may provide for the student a scheme more easy to grasp than the lengthy descriptions of the text-books. To those desirous of perpetuating eponymous nomenclature it may be pointed out that in very many parts of the body the superficial fascia may be separated into more than one layer by the intervention of encapsuled fat, and the ischio-rectal fossa may be recommended as a fruitful field for exploration. But possibly the underlying simplicity of the whole arrangement does not warrant these refinements of descriptive anatomy.

In the hand and foot the subcutaneous fat is, of course, not so abundant as it is in the lower part of the abdomen and thigh, and such fat as is always present in the sole and palm is held enmeshed in a peculiar dense fibrous sponge-work.

No fat quite like this is found in any other part of the body, but in the structure of the scalp certain general resemblances are to be found. In the palm of the hand the layer is usually thin, and the fat is present as little rounded masses, which give the subcutaneous tissues a coarsely granulated appearance. It is curious that the development of subcutaneous tissue in the hand is, as a rule, far greater in Europeans than it is in the Asiatic races. A general leanness characterises the hands of most Orientals, and it is somewhat strange that the thickening of the tissues of the hand which is so noteworthy in the manual labourer of Europe is present only to a very limited degree in the coolie class of any Asiatic race. In the sole of the foot, however, the fat layer is always very well developed, since here it forms a dense elastic pad, like an india-rubber sole, which minimises the shock of the body-weight striking the ground. The fat of the sole of the foot is laid down as rounded masses held tightly enmeshed in very dense fibrous tissue. The fat is encapsuled under some pressure, and wherever the tissues of

the sole of the foot are incised the fat will pout out as spherical masses when the restraining capsule is cut through with the knife. The density of the surrounding fibrous tissue is well known to every student of practical anatomy, and the func-

Fig. 32.—The crease lines of the hand to explain the nomenclature employed in the text. A, B, C, The distal, medial and proximal digital creases. D and E, The distal and proximal transverse palmar creases. F, G, H, The radial, medial and ulnar longitudinal palmar creases. K and L, The distal and proximal bracelet creases.

tional reality of the sole pad must have impressed every one who has been familiar with the unbooted natives of the rougher parts of the earth.

But though the fat and superficial fascia of the hand and foot show such well-marked functional peculiarities, these specialisa-

tions produce no alteration of the broad principles which apply to the formation of crease lines, and on palm and sole we may witness the development of those simple features that have been followed upon a larger scale in Holden's line. A line of comparative skin stasis is produced by an anchoring of the skin of the underlying tissues. The specialised smooth line of skin is bound down to the dense subcutaneous tissue, and this in turn is fixed to the deeper structures. An anchorage plane penetrates the tissues of the palm and creates a surface line of stasis. Now, in their essential structure the stasis planes of the palm and sole bear a very close resemblance to scars. When healing by fibrous tissue takes place through the several layers lying between muscles and skin, a fibrous union of the layers at the line of healing is apt to occur. A surgeon may make a line of stasis by dividing structures right down to the moving tendons, and every effort should be made by him to avoid creating stasis lines in directions which are opposed to those demanded by the functional use of the parts.

The crease lines of the palm in particular are very nicely adjusted stasis planes designed to permit the greatest freedom of flexure of the joints of the hand, and great disabilities may be inflicted upon the movements of the fingers by thoughtless interference with these planes. More than that, a very great deal of consideration should always be exercised before such a severe upset of mechanical conditions as that implied in making a scar at right angles through an existing skin crease is resorted to. To damage the existing crease lines is to impose a disability, but to create a new stasis line at right angles to the normal axis of stasis is to inflict a severe functional handicap. Those who with but little hesitation are prepared to slit up the whole palmar surface of a finger by a longitudinal incision in the middle line should be persuaded to make first-hand study of the structure and function of crease lines, for this would inevitably lead to an increased respect for these skin joints and a desire to make use of any route for operative procedure rather than that which inflicts the maximum of damage on them.

It is to be noted that there is a very general similarity in the main disposition of the palmar crease lines in all hands; there

is a very definitely established human type, which differs in many features from the type prevailing in the monkeys and anthropoid apes. But in the finer ramifications of the minor lines great individuality is displayed, and it is these myriad

Fig. 33.—Palm of the hand, showing what may be regarded as an average disposition of the flexure lines.

variations that provide a field for the palmist. Upon the fingers the main lines run transverse to the long axis of the finger, and three sets of lines are to be distinguished upon each finger. The line nearest to the tip of each finger—the distal digital line—which is usually rendered complex by several

loop-like offshoots, does not accurately mark the distal interphalangeal joint, for the skin joint is slightly further from the tip of the finger than is the underlying joint between the bones. A minor transverse line is sometimes present upon the pads of some of the fingers, and this line at times marks the joints with great accuracy; but it is too inconstant to afford a reliable guide to the joints, and often it is present upon one hand and not upon the other. It is more commonly seen on the index finger situated a few millimetres nearer to the tip of the finger than the distal digital line, and usually it is a perfectly simple linear crease.

The second set of lines, the medial digital crease, is typically double upon all the fingers. Numerous fine lines go to the making of the main lines, and between these two main lines is an area of fine flexible skin. The relation of these lines to the middle interphalangeal joint is complex. The line nearest to the root of the finger is placed over the head of the proximal phalanx, and, as a rule, the line nearest the tip of the finger nearly marks the site of the joint. But some variation is shown in skiagrams. In the hand of a working man (Private T. P.) in which the fingers were short, stubby, and powerful, and where the palmar skin was thickened, both lines lay nearer to the root of the fingers than the site of the joint. But in hands which have longer fingers, and a softer palmar skin, the line nearer to the tip of the finger may be taken as marking with fair accuracy the joint between the two bones.

The surgical teaching with regard to the position of these lines is by no means uniform. The double lines are said to be "exactly opposite the first interphalangeal joint" (Treves), and the line nearest the root of the finger is figured as lying directly over the gap between the two bones (see Fig. 36). But this is certainly not the typical arrangement, for it is the line nearest the tip of the finger, and not the one nearest the base, which coincides more accurately with the actual bony joint. It is, however, at the crease nearer the base of the finger that the maximum of skin folding occurs when the finger is bent, and it will be noticed that in most fingers the crease line of full flexion points straight to the middle of the knuckle, and the

prominence of the knuckle is always made by the head of the bone behind, and not by the base of the bone in front.

The basal digital crease line is one of varying complexity. Upon the index finger it is usually single. The single line is chain-like, and, as a rule, is the most oblique of all the digital creases, for, instead of being directed at right angles to the long axis of the finger, it is generally slanted so that, if its axis were produced to the ulnar side, it would intersect the pad of the little finger. Upon the middle finger the basal digital crease is practically always double, and the same condition is seen with slightly less constancy upon the ring finger. The added line in these cases is a simple linear crease situated some three millimetres nearer to the tip of the finger. Upon the little finger the basal line is usually single, but is extremely complex, for it is composed of interlacing minor creases which form a flexure fold of some considerable breadth. None of these basal digital lines has the least pretension to marking the site of the metacarpo-phalangeal joints, although at least one current text-book of Surgical Anatomy, designed to instruct the operating surgeon, figures these joints as lying immediately beneath the creases. The basal creases correspond to the extremity of the palm of the hand, being upon a level with the free edges of the web of the fingers, and they are situated almost three-quarters of an inch nearer to the tips of the fingers than the line of the joints. As a rule, they are somewhat to the proximal side of the mid-point

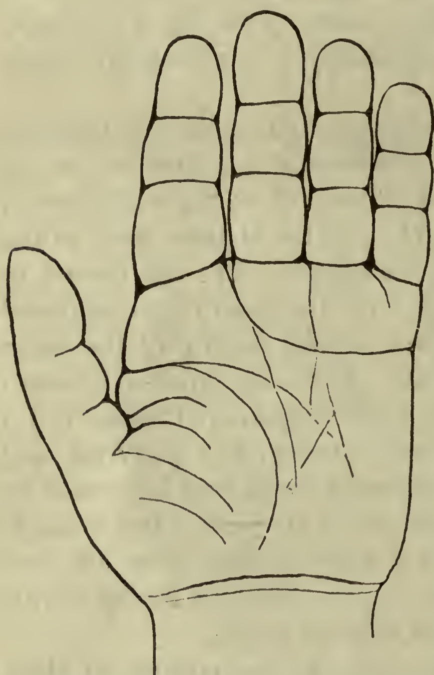

Fig. 34.—The palmar flexure lines of a human fœtus, 12 cm. R.V. length.

of the proximal phalanx, the average division of the bone by the crease line being about one-third to the proximal side and two-thirds to the distal side.

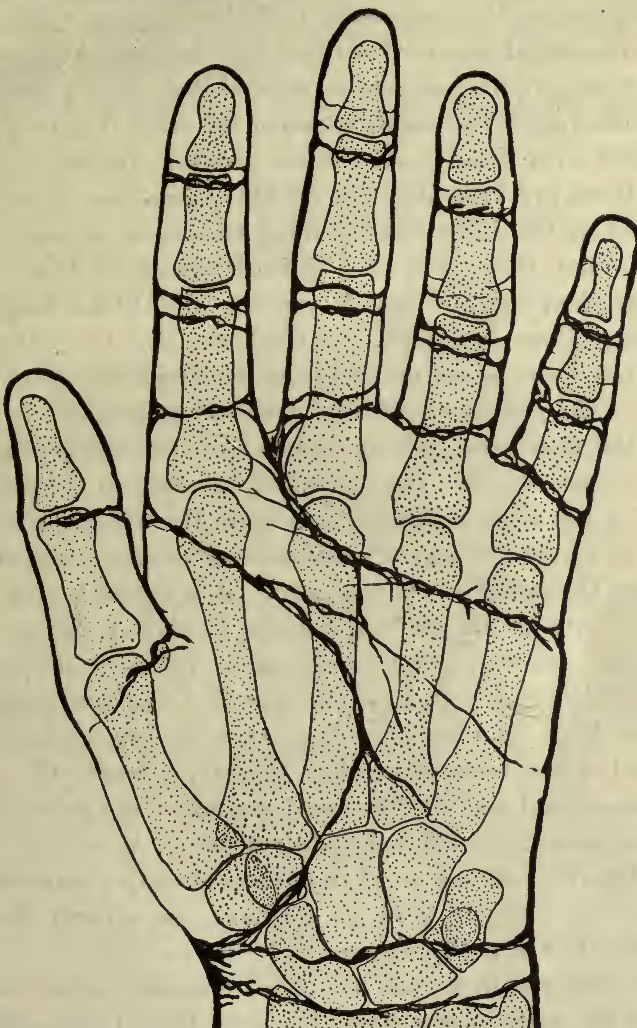

Fig. 35.—The relation of the palmar lines to the bony elements of the hand. Case of T. P. The fingers are short, and the medial digital crease is situated nearer to the base of the finger than the medial interphalangeal joint. Reconstructed from X-ray plates.

In dealing with the complex and important palmar crease lines some attempt at defining a precise nomenclature is needed. At present one may say that there is no generally used termino-

logy for the naming of these lines. We cannot refer in precise work to the "line of life," and yet we have no adequate substitutes to indicate these creases, which are of importance to the anthropologist, the anatomist, and the surgeon. Although in the human hand none of these lines run accurately in a transverse or in a longitudinal direction, nevertheless their general trend is so definitely in the one direction or the other that they may be classified into these two distinct groups. Of the transverse lines there are typically two on the palm, and these we will indicate as the distal and proximal transverse creases. Of the longitudinal lines there are definite traces of three groups, distinguished as the radial, medial, and ulnar longitudinal creases. There are other, less constant, and less conspicuous lines, but these do not detract from the simplicity of the general trend of the palmar crease lines into two main sets.

Of the transverse palmar creases the most interesting is the *distal transverse line*—the one which is situated nearest to the bases of the fingers. This starts upon the ulnar border of the hand as a rather complex chainwork of smaller lines, and runs towards the radial side of the palm. It is named by the palmist as the "line of Heart." Its course is curved, for its general trend is to turn towards the roots of the fingers as it approaches the radial border. It is in this curved trend that its greatest interest lies. In what one might term its typical human condition the line turns somewhat abruptly towards the roots of the fingers and ends at the anterior limit of the palm upon the web between the index and middle fingers. As it turns towards this cleft it usually gives off from its convexity a series of minor crease lines, which tend to continue its general transverse direction to the radial border.

The proximal transverse line is more marked upon the radial side of the hand, and it starts in a complicated chainwork upon the radial border about as far from the index basal digital crease as the distal transverse line starts from the basal digital crease of the little finger upon the ulnar side. This is the palmist's "line of Head." Its origin is typically blended with that of the radial longitudinal crease, and for a space of about an inch these two lines are merged in a common crease. When

the two lines become dissociated, the proximal transverse line sweeps with a gentle curve concave towards the wrist; towards the ulnar side, and after a course which is usually simple and linear, it becomes lost upon the pad of the ulnar border of the hand (hypothenar eminence).

The radial longitudinal line, starting in common with the

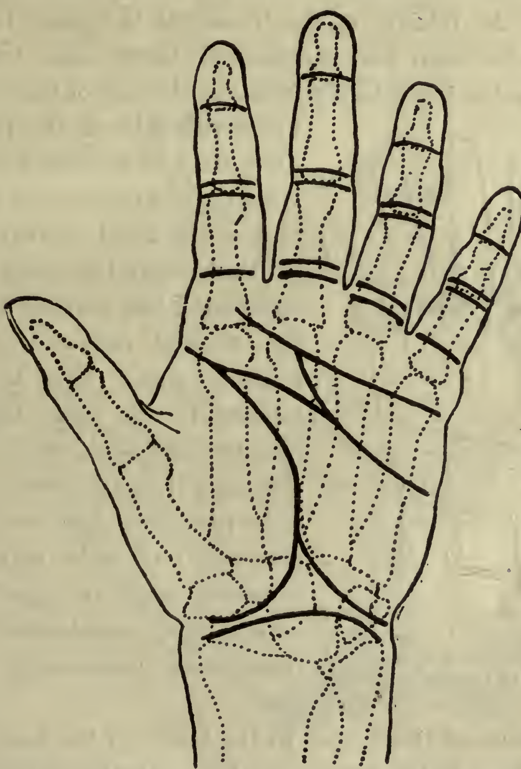

FIG. 36.—The relation of the palmar lines to the bony elements of the hand according to Treves. (From Treves' "Surgical Applied Anatomy.")

proximal transverse line, encircles the ball of the thumb, or thenar eminence, running with an even curve around the pad formed by the thenar muscles. This is the palmist's "line of Life."

The medial longitudinal line starts, as a rule, from the cleft between the index and middle fingers, in common with the upturned end of the distal transverse line, and runs rather obliquely

along the palm nearly parallel to the radial longitudinal line. This is the palmist's "line of Fate, or line of Saturn."

The ulnar longitudinal line starts near to the cleft between the middle and ring fingers, and runs nearly parallel to the other two longitudinal lines. It is, as a rule, but faintly marked, and to the palmist it is known as the "line of the Sun, or of Fortune."

The transverse lines, both distal and proximal, are formed mainly by the folding of the tissues of the palm by flexion of the joints between the metacarpal bones and the proximal phalanges; but they do not indicate the line of this row of joints upon the skin of the palm. Both lines may be regarded as tokens of what may be termed the longitudinal arch of the hand, as being produced by that normal bending in the long axis of the hand which brings about the normal curve of the hollow arched palm. This arch may be likened to the much more definite longitudinal arch of the foot, and although it is a feature of considerable practical importance, it has received but little attention from surgeons, since its significance is so completely overshadowed by the much more conspicuous arch of the foot.

Fig. 37.—The relation of the skeleton of the hand to the skin of the palm according to a current text-book of surgical anatomy.

The relation of these lines to the bones of the hand is worthy of note. The distal transverse line, starting upon the ulnar side of the hand, runs across the junction of head and shaft of the 5th and 4th metacarpals, and then, passing obliquely across the head of the 3rd metacarpal, just crosses the radial side of the base of the proximal phalanx of the middle finger, and passes to the cleft between this finger and the index. The proximal transverse line upon the radial side of the palm divides the head from the shaft of the 2nd metacarpal, and then, inclining towards the wrist, cuts across the shafts of the 3rd and 4th and 5th metacarpals, so that, on the average, it crosses the

upper third of the 3rd, the middle of the 4th, and the lower third of the 5th. The relation of these lines to the bones as stated in these terms is sufficiently constant to serve as a surgical guide to the position of the bones and joints. But some variation is present in the disposition of the distal transverse

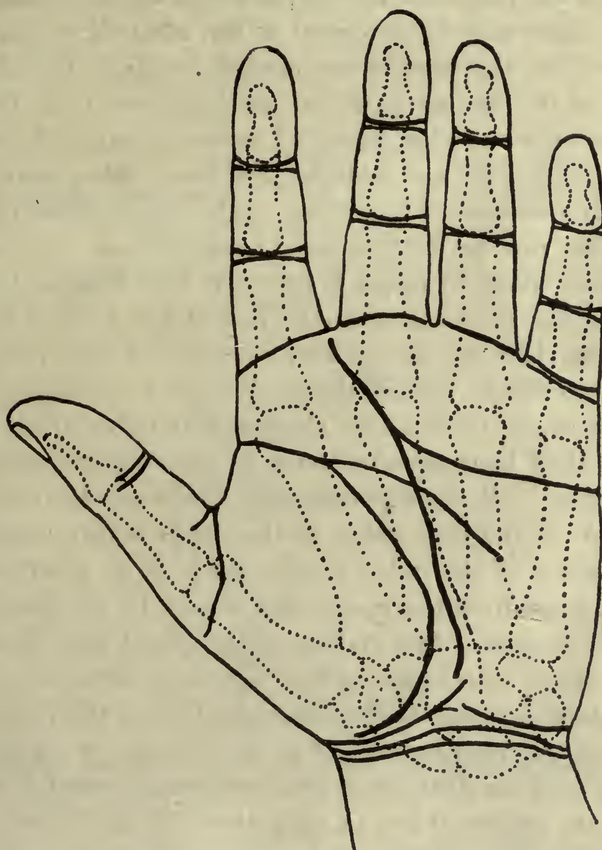

Fig. 38.—The relation of the palmar lines to the bony elements of the hand according to Sir George Thane. (From Quain's "Anatomy.")

line. In some people this crease runs from ulnar border to radial border across the palm, and does not turn to the cleft between the index and middle fingers, and in many, although it takes its normal turn to this cleft, it is also continued with more or less definite directness towards the radial side of the palm. Almost always it shows some tendency towards branch-

ing at its radial extremity. Variable though this line may be, there can be no doubt that its typical human condition is displayed in the presence of an unbroken curved course across the palm, the concavity of the curve being directed towards the fingers, and the two extremities of the curve cutting the ulnar margin of the hand and the cleft between the index and middle fingers. This may be described as the ideal human form, and it differs from that seen in any monkey or ape. The transverse creases of the human palm are distinguished from the corresponding creases in the hands of monkeys and anthropoids by their curved form and oblique direction. This distinction is especially conspicuous in the case of the distal transverse crease, for this line runs perfectly straight across the palm of a monkey's hand from ulnar to radial border. It is a human distinction that this line does not cross the pad at the base of the index finger, and here we see another evidence of the specialisation of this peculiarly human digit. We have previously noticed how this finger tends to be elongated and specialised in Man, and we shall have occasion later to note the specialisation of its muscles. All these peculiarities are dependent upon each other. It is the disposition of the muscles that brings about the aloofness of the index finger, and it is its aloofness which keeps it apart from the crease line shared by the middle, ring, and little fingers. The ending of the distal transverse crease in the second interdigital cleft is a human distinction, and for the anatomist it signifies the specialisation of the index finger; it tells of the independence of its movements, of its specialised muscles, and its distinction as a pointing or scratching digit; but for the palmist it has an altogether different meaning. The work on palmistry which I have taken for my guide in this matter invariably represents this line in the ape condition, but makes it end upon the pad at the base of the index finger rather than on the radial border of the palm. The line is said to be "really good" when it ends upon this pad, but when it ends nearer to the base of the middle finger "we may premise a strong feeling of attachment or love, but of a sensual rather than of a domestic type." It is curious that the ape condition should be taken as the normal, and still more strange that this

type should be considered to denote the ideal attitude in affairs of the heart. Were we to follow our guide in this instance, it would confidently be asserted that, compared with the present author, the average chimpanzee was a paragon of connubial love. If we must be taught by one science that we are the immediate descendants of the anthropoid apes, it is hard that we should be told by another that in the process of descent our " feeling of attachment or love " has been changed from a domestic to

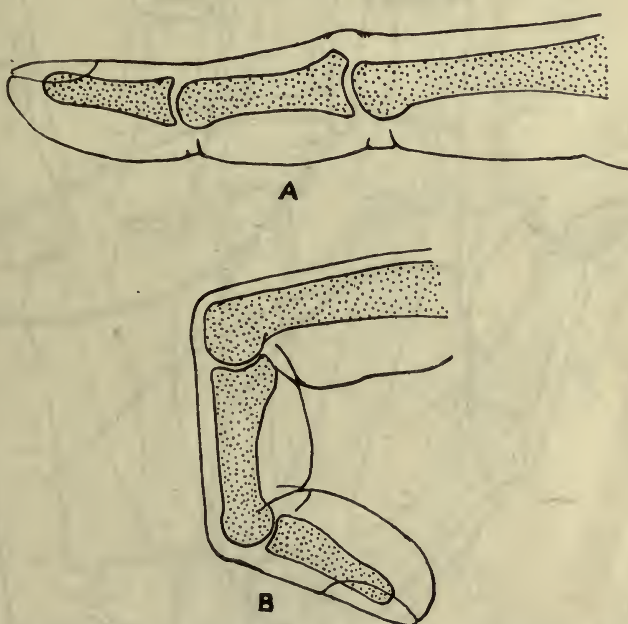

Fig. 39.—The index finger. (A) extended and (B) flexed, to show the relation of the flexure lines to the interphalangeal joints. Traced from X-rays.

a sensual type. In the monkey the specialisations of the index finger do not exist ; a common flexure line embraces the bases of all the fingers, and there is no individuality of the movements of the pointing digit. In Man alone is this finger held aloof from its fellows, and in Man alone does the distal transverse crease turn from the palm so as to avoid the base of this finger. The practical importance of these things will be discussed later on. Here it is only necessary to direct attention to the fact that when the fingers are slightly flexed, so that the hand takes up

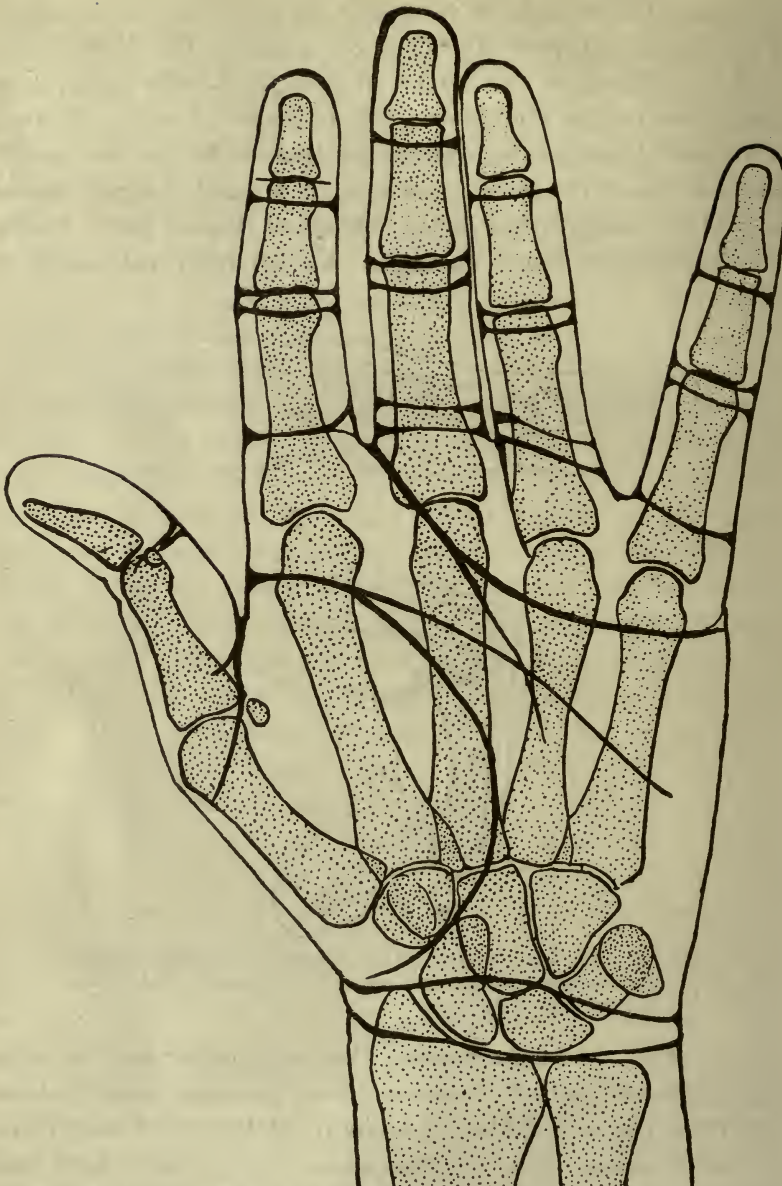

FIG. 40.—The relation of the flexure lines to the bony elements of the hand. Tracing from a radiograph of a hand which may be regarded as of average proportions.

a comfortable and unstrained attitude, it will be noticed that the little, ring, and middle fingers are bent in towards the palm

more markedly than is the index finger. The index lags behind in that degree of flexion which is present when a hand takes up a position of comfort and rest.

The proximal transverse line presents considerable variations in different hands, and to all the variations the most striking interpretations are given by students of chiromancy; but with these we will not concern ourselves.

FIG. 41.—Crease lines on a human hand (M. E.) which are disposed in a simian manner. The distal transverse line runs straight across the palm from ulnar to radial side.

The radial longitudinal crease is an interesting one, since its relation to, and causation by, the muscles of the thumb is so particularly striking. Upon the radial side of the hand its origin is usually made in common with the proximal transverse crease, and the common stem of the two creases passes across the junction of head and shaft of the index metacarpal. It then curves into the palm of the hand surrounding the thenar muscles, and passes, as a rule, to the ulnar margin of the metacarpal of the middle finger. From this point it curves back again towards the radial border of the hand, crossing the joint between the os magnum and the 3rd metacarpal, and then over the joint between the trapezoid and trapezium of the second row and the scaphoid of the first row of the carpus. Its relation to this joint appears from skiagrams to be peculiarly constant.

It then passes below the prominence caused by the thumb muscles, sometimes joining a transverse flexure line at the wrist. The excursion of this line towards the centre of the palm varies with the degree of development of the short muscles of the thumb, and for this reason it is commonly dissimilar upon the two hands. In the right hand the thumb muscles are usually better developed than they are in the left hand. As a consequence of this the crease extends further into the palm of the right hand, and not uncommonly it joins for a short distance the medial longitudinal crease. In the language of palmistry, the Line of Fate runs into the Line of Life, and this is obviously a very horrible result to be produced merely by the exercise of the thumb muscles. The medial and ulnar longitudinal creases find their chief interest as being surface evidences of the transverse arch of the hand. Our metacarpal bones are not held side to side so as to form a plane surface, but they are arranged in a gentle curve, which is easily appreciated by examining the knuckles of the clenched fist. This transverse curve is a thing of the utmost importance in the proper functioning of the hand, and it cannot be insisted on too strongly that a palm hollow from side to side is a necessary attribute of a perfectly mobile hand. In the action of producing a hollowed palm these two lines are brought into evidence. The medial crease arises, in common with the distal transverse line, at the cleft between the index and middle fingers, while the ulnar crease arises in the neighbourhood of the cleft between the middle and ring fingers. Both are well marked in the fœtal hand, but they are subject to considerable variations in the hands of adults.

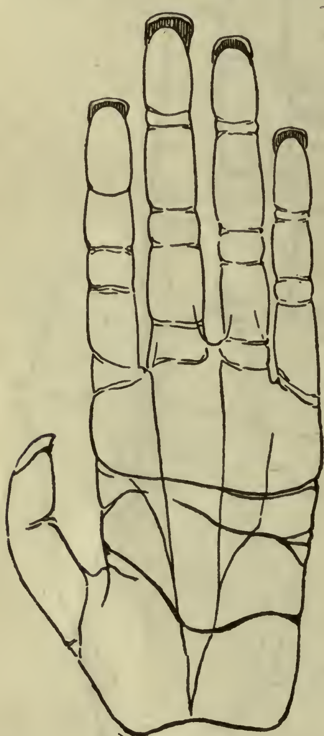

Fig. 42.—The palm of the left hand of a young female Chimpanzee to show the flexure lines.

Two other crease lines need mention here, although they do not, strictly speaking, belong to the palm. These are the bracelet creases of the wrist, which are known to the palmist as the bracelets of Life, and which are distinguished among flexure folds by the extraordinary constancy with which they mark joint lines. Typically there are two crease lines at the wrist. The distal bracelet separates the palm of the hand from the skin of the wrist, and the proximal bracelet runs across the skin of the forearm, about one centimetre and a half above the distal crease.

Fig. 43.—Sole of the foot of a human fœtus of 12 cm. R.V. length.

The proximal crease follows very accurately the line of the wrist joint, for it passes in the middle line of the forearm between the upper surfaces of the scaphoid and semilunar and the lower surface of the radius. It is a common and very natural mistake to assume that the distal crease line marks this joint, but this line passes with great constancy along the lower articular surface of the semilunar and separates this bone from the cuneiform and os magnum. The semilunar bone therefore lies in the mid-line exactly between these two crease lines, and this position is a good deal further up the forearm than most people imagine, even when they have completed a course of anatomy as ordinarily conducted in the dissecting room.

The crease lines upon the soles of the feet are not nearly so complex, so constant, or so well marked as those upon the palm of the hand. This state of affairs is the natural outcome of the loss of mobility which the human foot has undergone in its specialisation purely as a supporting organ.

It is the new-born child whose foot shows to the greatest advantage the lines which may be described as typically human, for mobility decreases with age, and with decreasing mobility the lines tend to become less and less evident. Just as in the hand, the plantar lines are clearly divided into two sets :

a transverse set, caused by flexion, and a longitudinal set, caused by the movement of bringing all the digits together and cramping the two sides of the foot towards each other. The transverse lines are the skin folds of the longitudinal arch of the foot, while the longitudinal ones belong to the transverse arch. As in the hand, there are usually two transverse lines, the proximal crease and the distal crease. The distal crease starts upon the fibular border of the foot beneath the base of the little toe, and passing inwards across the sole, ends at the inter-digital cleft between the big toe and its neighbour. The proximal crease is far less constant even in the child, and in the adult it is frequently lost or replaced by a series of indistinct lines. It also starts upon the fibular side of the foot a short distance nearer to the heel than the distal crease, and cuts fairly straight across the sole, but usually it is lost before it reaches the tibial longitudinal crease. It may, however, traverse the whole breadth of the sole, running into a crease which not uncommonly crosses behind the "ball" of the great toe. Of the longitudinal creases two are usually well marked and a third is occasionally present. The most conspicuous of the longitudinal creases corresponds to the radial longitudinal line of the palm, and is the adduction crease of the big toe. This line may be named the tibial longitudinal crease. The medial longitudinal crease corresponds to the same crease in the palm, and starting between the second and third toes, it ends by running into the tibial crease. The third, or fibular, longitudinal crease, when it is present, is to be seen as a shallow furrow running to the

Fig. 44.—Sole of the foot of a human fœtus of 15 cm. R.V. length.

tibial side of the base of the little toe. The flexure creases of the toes are of particular interest. The big toe has the two creases corresponding to those of the thumb. The second, third, and fourth toes show the three creases characteristic of the fingers; but the little toe lacks the middle crease even in the fœtus and young child. This fact is, of course, in harmony with

Fig. 45.—The sole of a child's foot to show the typical flexure lines.

Fig. 46.—The sole of the foot of a young female Chimpanzee to show the flexure lines.

the tendency to the loss of one bony joint which has been seen to be characteristic of this rudimentary digit.

Only two further questions need discussion here, the first, When are these lines first formed? and the second, Are they alterable once they have become established? Both can be answered very definitely. The main crease lines are developed very early in fœtal life, and they appear upon the palm before this is the site of any active movements. In the individual

they are therefore not caused by the actual movements of the joints of the developing hand, but are developed as a heritage, which may be used and modified by the individual when the muscles begin to actively work upon the joints of the hand. They first appear soon after the hand is fashioned as a digitate member, and by the eighth week of fœtal life they may readily be distinguished. The radial longitudinal crease is the first to become well marked, and after it the distal transverse crease and then the proximal transverse crease become conspicuous. Long before pregnancy is half-way through they are established in their characteristic adult form. That they may be altered by occupation is obvious to any one who has studied the hands of people employed in various skilled manual employments. That they may be altered with astonishing rapidity in cases of actual paralysis of various muscles of the hand, and in certain diseases of the nervous system, is familiar to every physician.

CHAPTER VIII.

THE PAPILLARY RIDGES.

In addition to the flexure lines, both fine and coarse, which we have already noticed upon the palm and sole, there is a most complicated system of ridges and furrows—the papillary ridges and papillary furrows—which traverse the whole of what may be termed the grasping surface of the hand and foot.

These furrows and ridges form very complex patterns, and it is by no means easy to detect any underlying system which accounts for their disposition. In a very general way the papillary patterns have a relation to the flexure patterns, since the trend of papillary lines is roughly parallel to the trend of the flexure lines in places where no great complexity of the systems is attained.

Each papillary ridge is composed of a linear thickening of the horny layers of the epidermis separated from its neighbours by an epidermal depression, and below each ridge is a corresponding thickening formed from the deeper layers of the epidermis. A papillary ridge is therefore a linear thickening of the epidermis both above and below the general surface of the skin. Through the thickness of the ridge the ducts of the sweat glands open in regular linear series along the summit of the ridge, and therefore these ridges may be regarded as the nipple-like orifices of the ducts fused in linear series. The appearance of the little mouths of the ducts when the hand is moist with perspiration is familiar to all, and even in the absence of perspiration the fine dotting of the ridges by the duct openings is very easily detected.

Papillary ridges are especially well developed upon the pads of the terminal joints of the digits, and upon all the eminences of the palm. They are, as a rule, less well developed upon the hollow of the centre of the palm and upon the two basal segments of the fingers; and over those areas of palm and sole that

are not brought into contact with objects upon which a hold is to be secured the lines are absent altogether. Upon the pads of the finger-tips the lines attain their maximum complexity, and here they tend to be twisted into little vortices of varying form, direction, and elaboration. With all their twisted nature, however, a simple ground plan will be found to prevail as a basis

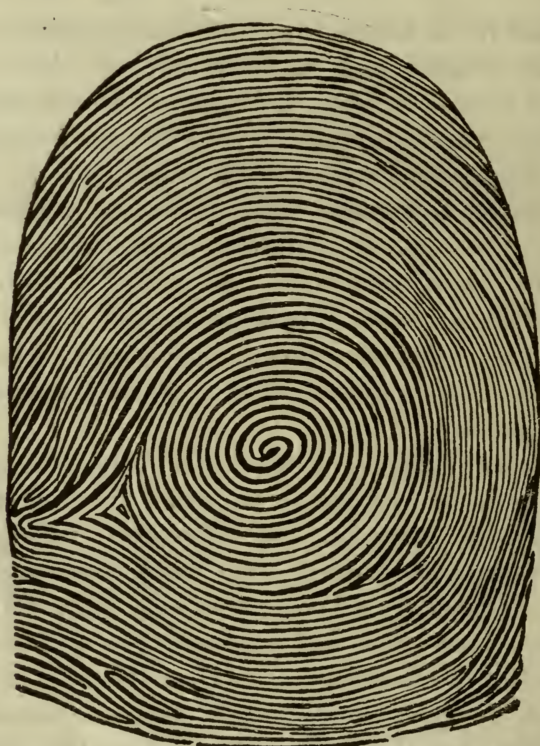

Fig. 47.—The arrangement of the papillary ridges on the apical pad of an individual left index finger.

for them all. It will be seen that the ridges at the base of the terminal phalanx run transverse across the finger parallel to the distal digital flexure line, while those at the tip run with a curve that marches with the curvature of the end of the finger. Traced from tip to base, these curved lines will be seen to run upon either side of the finger to meet the transverse lines towards their two extremities. In this way an enclosed space tends to be formed upon the terminal pad of each finger, the space

being bounded distally by the most proximal curved line, and proximally by the most distal transverse line. These lines meet at two angles, one on the radial side and the other on the ulnar side of the finger-tip. Either angle may fail to be developed, for on one side or the other the distal bounding line may sweep round and join the transverse line with an even curve. Within the space so enclosed is a series of lines which may be more or less definitely transverse, longitudinal, folded, circular, or spiral in one direction or the other.

By assigning initials to the bounding lines and to the angles a precise symbolic nomenclature has been systematised by a series of workers, most notably by Faulds, Galton, Testut, Fere, and Wilder. This nomenclature, which is written as a brief formula, covers all possible combinations and variations of the bounding lines, and the system is really one of extreme simplicity. The finger-print formulæ are often apt to strike the student as rather unnecessarily complex in appearance, but it should be explained that the apparent introduction of higher mathematics into this simple procedure is entirely due to the fact that the letters chosen by Galton to represent the different lines and angles were selected solely for the reason that they were symmetrical letters which were capable of reversal in the process of reproduction of the finger prints, and beyond that they have no significance.

Apparently Purkinje was one of the first to make any serious attempt at a precise classification of the papillary patterns. His work appeared in 1823, and it has formed the basis of many subsequent studies; but his methods have been superseded by those introduced by later workers. To Dr. Henry Faulds belongs the credit of first calling attention to the practical importance of papillary markings. In 1880 he pointed out in *Nature* the constancy and meaning of these marks, and later on the subject was carried further by Galton in his researches on "Personal Identification," published in 1888. Galton's studies brought to this subject sufficient scientific accuracy and a sufficiently stable basis to warrant all its modern specialised applications in the detection and recognition of criminals. We need not detail the actual system of classification

in vogue, for this may be studied to more advantage in the original papers cited. It is enough to say that, having regard only to the two lines and two angles which enclose the interspace on the terminal pads of the fingers, ten basal types may be sharply differentiated (see Fig. 48). By considering the pattern enclosed in the space as well as the boundaries of the space forty-one radically different variants have been recognised and classified. Each of these main types is subject to a host of minor modifications in individual finger-tips, and it will therefore be seen that the possible variations are legion, and that the precise pattern found in any person will be likely to be an individual peculiarity. More or less lines may go to the

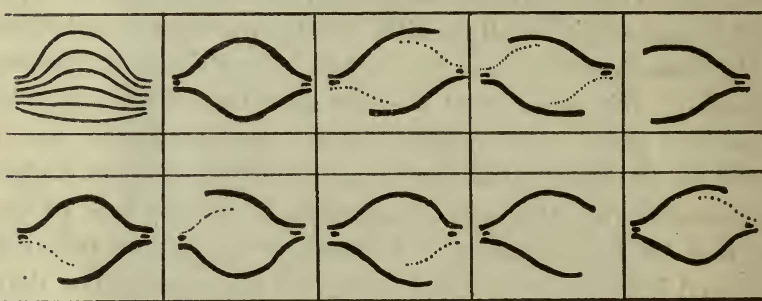

Fig. 48.—The ten distinctive types of enclosing lines of the apical pad pattern. (From Galton.)

making of patterns otherwise similar in general type; the nucleus of the pattern may be more distal or more proximal in the interspace, it may be wound either clockwise or counter-clockwise, and it may have various imperfections and peculiarities by reason of breaking, bending, or branching of the individual lines.

By a study of all these minutiæ the print of any individual finger-tip may be recognised with certainty among thousands of such prints, and when we remember that each of the ten digits shows its own peculiar pattern and its own distinctive minutiæ, the chance of coincidence in the patterns of any two individuals when the print of more than one finger is examined is practically negligible.

But there would be but little certainty in identification were the patterns to alter from time to time. It might be supposed

that so trivial a thing as the disposition of these ridges would not remain constant for very long periods. This point was settled by Sir J. Herschel and Galton by the re-examination of a large number of prints taken from several persons over a period extending to thirty years. Their conclusion, which has been amply confirmed, is that " from birth to death there is no change in the fundamental characteristics of the thumb and finger patterns, nor can there be any after death up to the time when the skin perishes through decomposition " (*Phil. Trans.*, Vol. 182, p. 13).

The question as to how far the patterns on the two hands resemble one another has received rather different answers. Galton, basing most of his conclusions on thumb prints, concluded that " patterns of similar kinds lie on the two thumbs in opposite directions "—*i.e.*, if a pattern is wound clockwise on the right thumb, a similar pattern wound counter-clockwise will be present on the left thumb. A symmetry between the two hands was, however, not found by Fere to occur with anything like constancy. This worker met with symmetry in the patterns of the two thumbs in 52·19 per cent. of all his cases, in the index finger in 41·09 per cent., in the middle finger in 56·59 per cent., in the ring finger in 52·74 per cent., and with the maximum of frequency in the little finger in 75·27 per cent. In my own case the spiral upon the right index is wound clockwise, whilst those on medius, annularis, and minimus are wound counter-clockwise, whereas on the left hand the index and the other three fingers have spirals that are all wound clockwise. A certain, but not very exact, degree of mirror symmetry is therefore seen in the middle, ring, and little fingers ; but with the index a very inexact direct symmetry is all that can be claimed. This failure of reversed likeness in the two index fingers, whereby the right index appears as a left-sided finger upon a right hand, is apparently not a rare phenomenon. Wilder has supposed that it is evidence in favour of the monozygotic origin of identical twins, but there is no doubt at all that the phenomenon occurs in the absence of any sort of suspicion that the individual has at any time been one of a pair of twins of any kind.

Galton's conclusion that " there is reason to believe that the patterns are hereditary " has been denied by Forgeot, but the work of Wilder would seem to show that inheritance plays a definite *rôle* in the disposition of the papillary ridges, and a study of the palm and sole patterns has been suggested as a means for determining cases of doubtful or disputed parentage (H. H. Newman).

Upon the palm of the hand the ridges are assembled into a series of " territories " which, in a very general way, are mapped out by the flexure creases, but which depart from this simple delimitation by an infinity of minor individual variations. In certain places these territories are separated from each other by lines which meet each other from three different directions, and these districts are known and classified as the " tri-radii." Besides the larger territories, loop patterns are found with a general rough constancy in definite sites upon the palm. These complexities occur for the most part on the interdigital pads at the bases of the four fingers, and upon the thenar and hypothenar eminences.

Upon the sole of the foot the territories are often extremely complicated. Looped systems are usually well developed at the bases of the toes, and the terminal pads of the toes are marked by patterns of a similar nature to those already noted on the fingers.

It is well known that the patterns both on sole and palm show well-marked racial variations, and from the classical researches of Alex in 1868 down to the most recent investigations by Kotando Hasebe, of Sendai, a vast amount of study has been devoted to the ethnological aspect of this question.

Amongst the members of the Primates papillary ridges of some form are universal. It is highly probable that the ridges developed upon the hands and feet of the lemurs are instances of convergent evolution when they are compared with the ridges upon the hands and feet of monkeys and apes. They subserve the same function, and they are developed for the same purpose, but the method of their production is not the same, since their relation to the mouths of the sweat glands is not that which we have seen in the human hand (Schlaginhavfen). In the monkeys

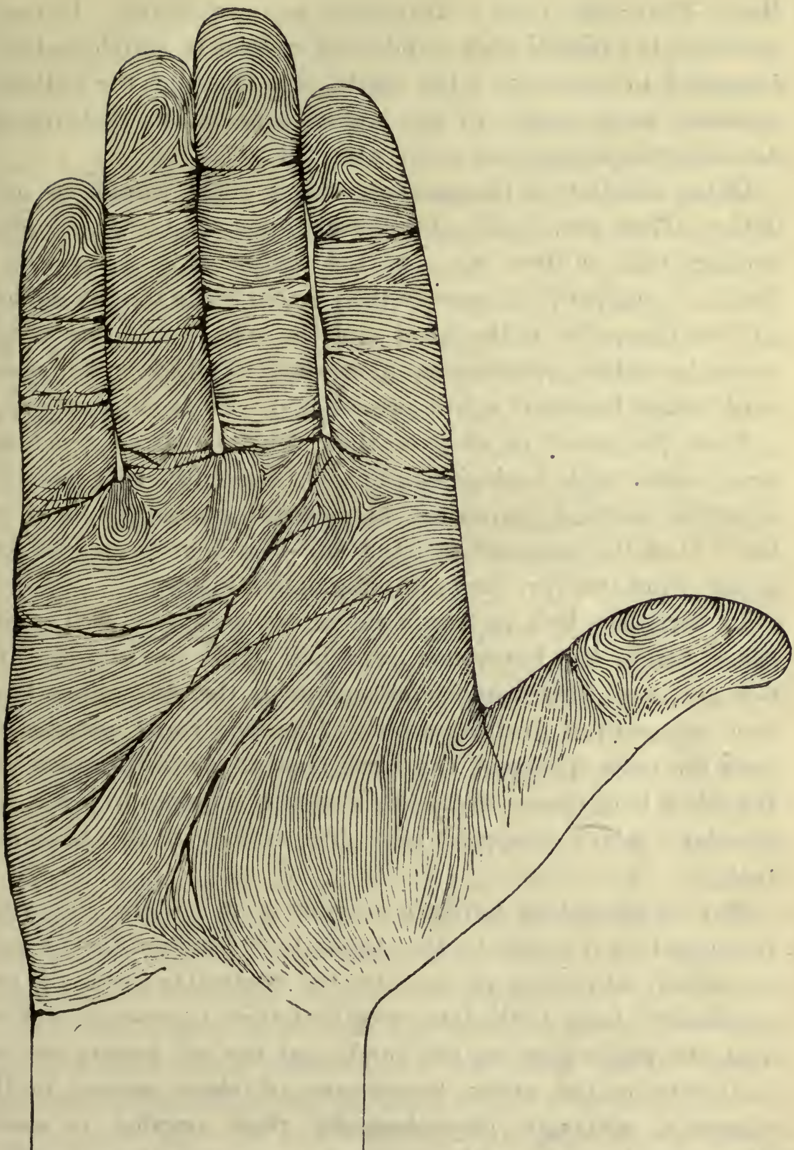

FIG. 49.—The papillary ridges upon the surface of a hand. The drawing is made from a cast lightly rubbed with fine graphite. The pattern is therefore reversed, the impression being of a left hand.

and apes the papillary lines are obviously identical structures, and equally certainly they are identical with those found in

Man. They differ only in disposition and complexity. In most monkeys the digital pads exhibit an extremely simple pattern elongated in the axis of the digits, and although the patterns approach more nearly to the human type in the Anthropoid Apes, human complexity is not attained to.

Of the function of the papillary ridges there cannot be any doubt. Their very precise distribution upon the tactile grasping surfaces tells of their use. As the handle of a weapon or a tool is " roughed " to improve the grip, so is the skin of all that part of the palm of the hand and the sole of the foot which comes in contact with objects upon which a hold is to be taken, made rough to ensure a firm, precise, and sensitive apposition.

From the point of view of their function these structures have considerable biological interest. Evidently they may be regarded as fairly primitive mammalian possessions, and we know that the mammalian hand and foot have been grasping organs from the very dawn of mammalian history.

In Man the whole system of ridges and grooves is well established before the fœtus has lived half of its interuterine life, but in a very large number of mammals the extremities have been so modified for the purpose of making rapid progression over the open spaces of the earth that all power of grasp has been lost long since. With the loss of the power to grasp the papillary ridges disappear from the surface of the hand and foot.

But an interesting corollary presents itself: If these lines are developed in response to the demands of function, could they be called into being *de novo* by the particular needs of any peculiar life-habit? We have seen that there is reason to believe that the ridges seen on the hands and feet of lemurs are not anatomically the strict homologues of those present in the monkeys, although physiologically their parallel is exact. Many people would not be prepared to entertain the supposition that the lemurine system of papillary ridges could be other than a manifestation of kinship to the monkeys. The lemurs are so generally regarded as being immediately ancestral to the monkeys that to suppose the ridges in the two groups to be fundamentally different developments would seem to be absurd.

But by going no further afield than the examination of the digital formula we have already been led to be somewhat cautious in attempting to derive the monkey hand from the lemur hand ; and a host of other anatomical details in other parts of the body point to a still greater need of caution in assuming that the lemurs are the ancestors of the monkeys, and that a structure seen in the one group has necessarily been derived from an apparently similar structure in the other. Within the limits of the Simiidæ we find from a study of the papillary ridges a very striking instance of convergence of structure in response to the demands of function. Certain of the South American monkeys, notably the Spider monkeys (Ateles) and the Woolly monkeys (Lagothrix), rely far more upon the grasp of the prehensile tail than they do upon the grasp of the hand. The Spider monkeys and Woolly monkeys have perfected their tail grasp so thoroughly that they have tended to sacrifice some of the primitive perfections of their hands, for the Woolly monkeys have an insignificant thumb, and the Spider monkeys have lost this most useful member altogether. Their tails have usurped the function of their hands—and therein lies a beautiful example of the wonderful adaptability of structure to function—for their tails have developed a perfect system of papillary ridges upon their grasping surface. The tip of the tail of the Spider monkey is the most wonderful mimic of a finger. The underside is naked, with a skin having exactly the texture and consistency of the skin of a finger, with flexure lines and with papillary ridges strikingly like those seen in the hand. But the ridges do not become arranged in rings or spirals, for they are disposed in a double series of lines, running obliquely across the breadth of the tail, and these ridges do not bear relation to the opening of the sweat glands as do the ridges on the fingers.

We might press the lesson to be derived from these monkeys still further ; for not only may papillary ridges be developed *de novo* in response to the demands made by function, but the whole complicated co-ordinate mechanism of a prehensile tail has been developed repeatedly in the phylum of the mammalia. Prehensile tails are developed independently in response to the demands of function in Marsupials of widely different types

(*Didelphys*, *Tarsipes*, *Dromicia*, etc.), in certain Carnivora (*Cercoleptes*), in some Rodentia (*Synetheres*), and in the New World Primates.

Consideration of these facts must temper the enthusiasm of any one who embarks upon the work of determining phylogenetic affinity merely by detecting superficial similarity in structure.

CHAPTER IX.

The Nails.

Nails and hairs are both specialisations of the horny layers of the epidermis, and although both are ranked as "protective" epidermal organs, their functions are very different. Hairs are protective inasmuch as they prevent the loss of body heat in a warm-blooded animal; but nails are protective in a far more active sense, since primitively they shield the tips of the digits from injury in warfare, both offensive and defensive, and in all the hazardous enterprises undertaken by the fingers and toes of every digitate vertebrate, no matter if it be a warm-blooded or a cold-blooded one. Whilst the possession of hairs is therefore limited to warm-blooded animals, and a hair covering is distinctive of the Mammals, nails are an early acquirement of the digitate vertebrates, and are present in Amphibians, Reptiles, Birds, and Mammals.

The most primitive nails seen in the Amphibia are of especial interest, since their flattened form demands that they be classed as nails and not as claws, as talons, or as hoofs. It has been noted (Goppert) that the flattened nails of such tailed amphibians as *Onychodactylus* are strikingly similar to those seen in some mammals; but nevertheless in the bulk of the digitate reptiles and in the lower mammals the horny appendages of the digits present, not a flattened spatulate form properly termed a nail, but a highly arched and pointed structure which is more justly termed a claw. Broadly speaking, true nails are present only in the Primates among the Mammals, and we are therefore faced with an exceedingly difficult problem, for it must be admitted that if a flattened nail be the primitive form, it is remarkable that this primitive type should be present only in the highest mammalian order. The nails of the Primates might conceivably be examples of the retention of an exceedingly primitive condition, or they might be specialisations which, in their completed form,

show a considerable resemblance to the primitive type. Which of these alternatives represents the true state of affairs is a matter upon which one can only speculate, since absolute proof for the claims of either supposition is lacking. If we review the whole sequence of the Primates arranged in their order of zoological classification, we are at once brought face to face with an exceedingly puzzling state of affairs. The lemurs possess flat nails, save where for some special purpose a claw is developed. There would seem to be no doubt whatever that the lemurine claws are functional specialisations, the lemurine nails representing the unmodified condition. Moreover, it may be asserted that, as a general rule, the function for which the claw is specially developed is that of scratching, and often for that peculiar act of scratching associated with the toilet of the hair.

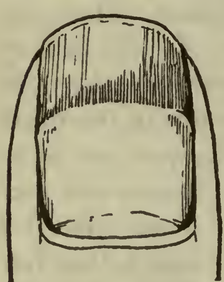

Fig. 50. — The right thumb-nail of a man whose right humerus was fractured by shrapnel on April 10th, 1918. By November 27th, 1918, the transverse groove had grown 10 mm. down the nail. The grooves upon the nails of the left hand had all been removed by growth.

But passing from the lemurs to the lowest members of the monkey series—the little marmosets (Hapale)—we find claws fully developed upon all the digits save the big toe. The New World monkeys (Platyrrhini), although generally said to possess nails, have them so highly arched that the dividing line between nails and claws is not easy to draw in these animals. The Old World monkeys and anthropoid apes (Catarrhini) show a greater ungual flattening, and in them the lemurine ideal of a nail is more nearly approached. Were we to judge, therefore, simply from a study of the monkey series, we should be forced to the conclusion that in the ascending scale of zoological classification of the Anthropoidea, or Haplorrhini (Pocock, 1918), we may witness with great perfection the evolution of the flattened nail from the more primitive arched claw. But a consideration of the lemurine condition must make us pause. We must take notice of many rather disconcerting facts before we assume with a light heart that the zoological classification of the Anthropoidea represents a true phylogenetic picture of

the monkey series, and we must be cautious in accepting any morphological dictum that asserts that the nail is the specialisation of the primitive mammalian claw. It is possible that our nails are the perfected product of the gradual evolutionary flattening of the arched claw seen in the marmosets ; but it is also not beyond the bounds of possibility that, being strikingly like the lemurine nail—and even having some resemblance to the most primitive type of non-mammalian nail—they may be singularly primitive and comparatively unmodified structures. To a consideration of this problem we will return later.

Essentially nails consist of a hardening of a layer (*stratum lucidum*) of the epidermis. The process of epidermal specialisation which results in nail formation starts in the human embryo at about the ninth week of development ; but no actual nail at all comparable in appearance to the familiar adult structure is present till another month has passed. The nail itself begins to develop below the surface layers of the skin, and so the little area of hardening is buried from view by the covering skin known as the eponychium. This little covered area of nail formation is situated nearer to the tip of the fœtal finger than is the nail of an adult, and it is marked off from the general surface of the skin of the finger by an infolded epidermal groove behind, a flattened depression in front, and a faint groove upon either side. The nail site now moves relatively further back along the dorsal surface of the finger, and assumes the position characteristic of the adult nail. This migration of the nail rudiment from the tip of the finger to its dorsal surface is perhaps not quite so extensive as was first claimed by Zander, and although it may be associated with the dorsal distribution of ventral nerve twigs to the finger-tips, it is no proof that our nails were ever claws, as Zander supposed. When the fœtal nail has reached its adult position its structure becomes more definite, the skin cells in the layer (*stratum lucidum*) destined to form the adult nail become specialised in form, and the horny substance known as eleidin is deposited in them. This little horny plaque is still, however, buried beneath the eponychium. During the fourth month the nail undergoes the same developmental phases as are seen in a more striking manner in

the case of teeth, hairs, and certain other epidermal structures; the nail is "cut" or erupted. The cutting of the nails consists in the pushing towards the surface of the growing horny mass and the parting of the eponychium over the centre of the nail area. The ruptured eponychium shrinks to the margins of the erupted nail, and the posterior infolded margin of the nail area persists as an epidermal layer overlying the surface of the root of the horny nail. This basal remnant of the eponychium persists at the nail root as that irregular margin of transparent skin which tends to overgrow the nails and which is known as the perionyx. The remnant of eponychium at the anterior end of the nail area at first constitutes a ridge similar to, but more conspicuous than, the perionyx. This heaped-up mass of cells (hyponychium) is often known as the "sole pad," since it forms the basis of the hoof in ungulate animals, but such a name must be used with caution, lest one may be led to assume that this eponychial mass represents in man the degenerated remains of a former functional structure. The fate of the so-called sole pad is determined by the forward growth of the nail, for at a later stage, when the anterior margin of the little nail plate begins to grow forward as a free edge, the sole pad becomes hidden beneath the protruding tip of the nail. In the fully formed nail the sole pad simply constitutes that little mass of irregularly thickened transparent skin beneath the free edge of the nail. But although the perionyx and the sole pad are mere remnants of the eponychial layers, through which the developing nail was cut, they are both of interest to the student of human anatomy. Both structures are very variably developed. Some persons, careful in the toilet of the nails, wage lifelong war against the growth of the perionyx, while some, not so concerned in these matters, have no need to pay attention to its repression, since its development is reduced to a minimum. Again, the

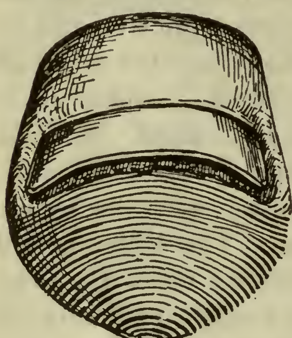

Fig. 51.—The tip of a finger, to show the so-called "sole-pad" beneath the free extremity of the nail.

growth of the perionyx may be very unequal upon different fingers, and whereas upon the thumb-nail its presence may be very slight indeed, upon the index it may be excessive.

The sole pad is of interest on account of its very curious overgrowth, which is typical of some nervous lesions, and for the fact that it must be peculiarly resistant to bacterial infection. In the ordinary course of nature every cutaneous irritation is scratched by the finger-nails, and every cutaneous irritant must at some time or other find its way beneath the nail margin in contact with the sole pad. Yet it is only occasionally—and usually when the natural resistance of the sole pad has been reduced, as by prolonged maceration in water—that this protective barrier is broken down and paronychia or whitlow results. For the practical anatomist, the growth of the eponychial remnants has a peculiar interest, since the use of formalin tends very remarkably to encourage the development or the retention of these epidermal products. The forward growth of the cornified nail plate which covers the embryonic sole pad continues during fœtal life, and by the time full term is reached the free tips of the nails have grown forward to reach the ends of the fingers. A new-born baby's nails are therefore perfect miniatures of adult nails, already capable of being used for scratching, and this is the first functional use to which they are put.

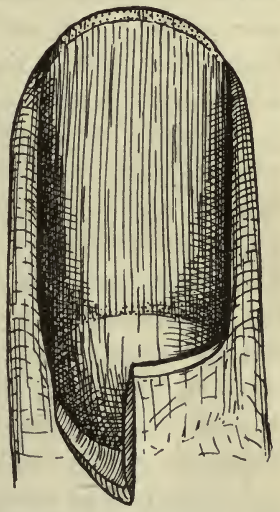

Fig. 52.—Dorsal aspect of a nail with the perionyx removed over one half to show the growing root of the nail and the lunule.

Throughout life the nails continue to grow. The process of cornification, which consists of a deposit of eleidin in the specialised cells differentiated from the deeper layers of the epidermis, is for ever going on beneath the skin of the base of the nail; and as this change takes place the tissues move slowly forward, so that the process of nail formation produces a growing nail. This forward migration of the deeper layers of the skin

over the dorsum of the terminal phalanx is a very wonderful thing, and the process has perhaps not received the attention that it deserves. The phenomenon is well illustrated by the following trivial circumstances. I was bitten on the right index finger by a chimpanzee on October 20th. One lower canine tooth penetrated the skin on the palmar surface of the terminal phalanx. The upper canine inflicted a slight scratch of the dorsal surface five millimetres above the root of the nail, and an incisor, which did not penetrate the skin, produced a small and sharply limited extravasation of blood in the deeper layers of the epidermis, which showed itself, after pressure had driven the blood from the surface of the skin, as a small bruise. Although the surface scratch and the deeper bruise were exactly alongside one another, it became evident as time passed that their relative positions were altering. The small surface scar remained upon its site of infliction, but the bruise appeared to be coming nearer to the surface and to be moving forward towards the root of the nail. In the course of a month the surface wound had disappeared in the ordinary process of healing, but during the whole time it was visible its position never changed. The mark of the canine upon the lower surface of the finger was distinct for three months, and during the whole of that time it remained exactly in the same position, nor is there any reason to believe its site would undergo much alteration, for a scar upon the dorsal surface of the terminal phalanx of the left middle finger has not appreciably shifted its position in thirty years. But by December 6th the little bruise had reached the nail base, and a small portion of it was incorporated in the "moon" of the growing nail. Another four months elapsed before the black mark had traversed the whole twelve millimetres of the nail.

Apparently this trivial chain of circumstances shows that the deeper layers of the epidermis over the dorsum of the terminal phalanx are undergoing two changes, for, in the first place, they are moving forward towards the nail bed, and, in the second place, they are undergoing cornification in process of being transformed into the hard transparent nail substance. It also seems to be clear that the more superficial layers of the skin are not taking part in these processes, or, at any rate, are

not participating to a greater extent than suffices for the production of the perionyx. In the normal process of growth the preparation of the nail substance is taking place beneath the skin of the terminal phalanx, and the tissues do not become fully cornified until the growth has pushed forward to the region of the perionyx. That portion of the growing nail in which the process of cornification is not yet completed is imperfectly transparent, and it presents an opaque, whitish appearance which gives rise to the " moon " of the nail. Moons are very variable in their development. They are more constantly present on the fingers than on the toes, and the big toe may be the only one which bears any sort of moon. Upon the hand they are most usually present on the thumb-nail and most commonly absent on the little finger. In size, colour, and form they also show variations.

The substance of the nail is therefore prepared at the nail root, and the extent of this root beneath the skin may be demonstrated by pressing upon the nail and observing how far back the skin of the terminal phalanx becomes depressed with the movement of the nail. Cornification commences here, and the tissues of the nail root are becoming rigid. At the site of the moon the newly grown nail is completely formed, but is not yet perfect, for its horny substance has not become fully transparent. As the nail grows forward from the moon to the free tip across the length of the nail bed it increases only in thickness by addition to its under-surface. This added growth from the whole area of the nail bed makes good the wear and tear to which the surface of the nail is exposed, and accounts for the fact that the nail is thicker at its free edge than it is at the root. The rate at which nails grow is extremely variable. They certainly grow faster in youth than they do in old age, and it has been determined that in people between seventy and eighty years of age the growth is only one half of that attained before the age of thirty. It has been asserted (Schmidt) that the growth is more rapid in the winter than in the summer, but the exact reverse is true in most cases. The finger-nails grow faster than the toe-nails, the difference in rate being almost four to one, and the nails of the right hand grow slightly faster than

those of the left. Again, the nails of all the fingers do not grow at the same rate, and the thumb-nail is usually the most rapidly growing of them all.

The average rate of growth, and the time taken for the complete formation of a nail, are very differently estimated by different authorities. According to Beclard, 70 days suffice for the growth of a finger-nail; but Sappey has extended the period to from 75 to 90 days, and Poirier to from 121 to 138. If a nail has been shed as the result of injury it will, however, be found that these estimates do not cover the time usually necessary for the completion of growth of an entirely new nail, since 180 days may well be occupied in the process.

Fig. 53.—Specimen showing overgrowth through neglect of the big toe-nail. The condition is known as onychogryphosis.

In a normal healthy, growing nail it may be reckoned that from $\frac{1}{32}$ to $\frac{1}{25}$ of an inch is produced every week, and this would mean that the entire exposed nail surface was renewed about every 87 to 112 days. Under certain circumstances, however, the growth may be greatly retarded, and much clinical interest attaches to the study of the rate of nail growth.

Since the moon represents that part of the nail which has been thrust forward from the root most recently, and in a state of incomplete cornification, it might be supposed that with an increased rate of growth of the nail the moon would tend to become more conspicuous. As a general rule, this supposition will be found to be true, and nails which have well-developed moons may be regarded as nails in which growth is proceeding rapidly. When no other nail possesses a moon, it will almost always be noticed that the more rapidly growing thumb-nail shows its presence.

It is common knowledge that nails which are not trimmed will overgrow in the most astonishing fashion. The enormous elongation of the nails of the cultured Chinese gentlemen is well known, and every medical student is familiar with the condition known as tramp's toe-nail, or ram's horn nail (onychogryphosis), which ranks among the curiosities of Medicine.

These cases attracted much attention from the older physicians, and Linden records the case of "a woman at Euchysen so careless of herself that she let her nails grow to that prodigious length that she could not go. A Chyrurgion was sent for to pare them, and 'my Father,' says he, 'carried away the Parings along with him.' The Parings of the thumb was two Thumbs long, a finger's breadth thick, solid about the roots, and thence compacted of several slates. The paring of the middle finger was as long as the first, but not so thick, yet very thick. None shorter than a thumb's length; that of the little toe, thicker than usually the thickest nail of the great toe. What grew in breadth was seen to be crooked within."

Normally the growth of the nail proceeds from a perfectly

FIG. 54.—Transverse section across a nail to show the relation of the horny nail to the underlying nail bed.

uniform and definitely limited area at the root, but it is not uncommon for the lateral margins of this area to present irregularities. At the edge of the area imperfect nail formations may occur which are not in complete continuity with the main nail root. In this way those irritating, partly detached formations known variously as "hangers," "hang-nails," "grannies," or "back friends" are developed. It may happen that the production of nail tissue does not take place perfectly evenly all over the bed of the nail root, and then the growing nail becomes marked by longitudinal ridges. Such ridges are extremely common in old people, and when unduly prominent in earlier life are often associated with a brittle condition of the nails, and are usually indications of that "fibrous diathesis" of the older school of medical thought which commonly denotes a rheumatic or gouty tendency. At times, and especially in

cases of nerve injury, the longitudinal ridges become broken in their length at regular intervals, and then the nails present a beaded appearance. If, however, the whole of the nail root temporarily performs its function of nail production in an irregular manner, then irregularities of nail surface will be evidenced in a transverse direction across the whole breadth of the nail. By some general upset of bodily well-being nail production may be temporarily impaired, and then the well-known transverse groove indicative of an illness is stamped upon the growing nails. These grooves have been especially conspicuous upon the nails of men wounded during the war, and often it has been possible to guess with some degree of accuracy at the date of wounding by an inspection of the finger-nails. The grooves are always deeper on the injured limb than they are upon the sound limb, and even if no nerves are involved in the destruction of tissues by the missile, the nail growth is always delayed upon the hand of the injured side. In cases of fracture caused by military projectiles these grooves are particularly conspicuous, and the retardation of nail growth is sometimes very remarkable. There is an old and widespread belief that these grooves, which are produced in the nail when a limb is broken, reach the free tip of the nail when the broken bones are firmly united, and were no other methods of diagnosis of union of fractures to hand, it is conceivable that the sign might be of use.

The transverse grooves upon the nails may be compared to the similar grooves which are sometimes present on the teeth, and both are signs of a period of imperfect tissue production caused by some upset of bodily well-being; but those on the teeth, appearing so long after the causative illness has passed, are apt to be dissociated from their cause in popular appreciations of pathology.

Other lowering factors more trivial than a serious illness, a fracture, or a wound may cause imperfections of nail growth, and these minor imperfections are of some interest. Various theories have been put forward to account for the presence of the white spots which sometimes appear in the nail substance. The theory which would seem to be perhaps the most absurd

of them all is the one which has always attracted my sympathy, and is the one which I believe to be well supported by observed facts. What folk-lore may be centred about the "gift, friend, foe, letter-to-come, journey-to-go" interpretation of these little marks still awaits, I believe, the investigation of the anthropologist. But that the stress which leads to their production is often a mental rather than a physical one may perhaps find expression in this popular explanation of their significance. Worry and anxiety certainly seem to play a part in their causation, and trivial though they may appear, they are worthy of attention from any one who would study the patient as well as the disease.

The perfect nail is transparent, and through its thickness the colour of the underlying vascular nail bed appears as a delicate pink. It was well known to Hippocrates that this arrangement afforded the physician an excellent opportunity for actually seeing the colour of the blood in the capillaries of the nail bed. Diemerbroeck has observed "that though the colour of the nails seems to be changed in several Distempers of the Body, yet that is no real Change of the Colour in their Substance, but only of the Humors that lie under, for that the nails are transparent, so that the Colour of the Blood or any other Humors underneath appears through them. And therefore in a Syncope or the beginning of a Quartan Ague, by reason of the little Blood that comes to those parts, they look pale; in Plethories, by reason of the great quantity of Blood, they look Red; and in Cacochymies they look of an ill colour" ("Anatomy," 1694, Book IX., Chap. XXIV., p. 608). The medical student should be well aware of the valuable information concerning the circulatory system which may be gained from a careful study of the vascular nail bed.

That the nail bed is highly sensitive is familiar to every one, and it is easy to understand how ancient anatomists came to believe that the nails were the termination of nerves, while many seventeenth century writers regarded them as specially developed to protect the nerve endings.

That nails are primarily protective in function and that the tips of digits have of necessity to be highly endowed with tactile

sensibility are of course elementary facts, and so we will not widely differ from the opinion of the older anatomists "that unless those extream Parts of the Fingers were guarded by the nails, the general Uses to which they are put would cause a continual Extremity of Pain, and render the ends of the Fingers altogether useless, and this is their Primary Office." With the statement that "their secondary use is for scratching" I am in entire agreement. In this conclusion I have great sympathy for "a Lover of Physick and Surgery," who in 1724 published a pamphlet entitled "An Essay concerning the Infinite Wisdom of God, manifested in the Contrivance and Structure of the Skin of Human Bodies." This author finds evidence that nails were "created with wisdom," since they "are as weapons to

Fig. 55.—Longitudinal section of a nail and the nail bed to show the structure of the root of the nail.

defend us from the trouble that arises to us from some small living Creatures that often make their Habitation upon the Surface of our Bodies and to allay the uneasy Titillation by Scratching." Preening organs and hair combs are structures of peculiar interest from their widespread occurrence and their variety of form in the animal kingdom. The toilet of the hair, the skin, and the feathers demands the development or adaptation of special structures for its proper performance; and although the beaks and claws of birds and mammals have a wide range of other functions, their use as toilet instruments is by no means an insignificant one. The specialisation of a definite scratching claw is a phenomenon met with both in birds and mammals, and a little reflection will convince most people that two of our fingers are most usually called upon to perform this office. The little finger has a mission especially connected with

the external auditory meatus, and this mission led to the older anatomists naming it auricularis. The index finger is, however, pre-eminently the scratching digit. Man has no claws, but it must bc owned that the high-pitched nails of index and minimus are more nearly approximations to claws than are the nails of the other digits.

CHAPTER X.

Hairs.

In the days when Man was considered as a being that was altogether detached from the rest of the animal kingdom many ingenious speculations were put forward to account for the very typical animal hair which is present, in greater or less degree, upon the surface of our bodies. It was developed to prevent friction according to some, but the most prevalent explanation was that it was provided for decency, and there was much to render this view acceptable. Then came a complete reversal of mental attitude, and the body hair of Man became one of the most obvious of the many sign-posts which marked our very recent rise from an ancestral anthropoid.

To-day we need not go to either of these extremes, since for us hair is the hall mark of the mammal, and our ingenuity now must be exercised rather in determining why Man has so little body hair than why he has any at all.

The hairy coats of the mammals, like the feathers of birds, were begot, not as ornaments, nor as coverers of shame. It matters not what secondary use may afterwards be made of hairs and feathers ; their primitive function is to conserve that body heat produced by the co-ordinated activities of perfected respiratory and circulatory systems.

The early Jurassic precursors of the mammals were generalised reptiles, which led a comparatively sluggish life. Their bodily activities were limited by the fact that their limbs were not fully perfected to support their body weight ; they did not constantly carry their bodies sheer of the ground. In spurts of activity, no doubt, they raised their bodies up and advanced by bearing their weight upon their limbs ; but, in general, their progress was made, as it is in modern reptiles, by dragging the greater part of the body length along the ground. It was only when the position of activity became habitual, and when the animal

stood always clear of the ground, that that real activity which demanded and initiated a more rapid metabolism was developed. It was this development that begot the real mammal from the very mammalian Jurassic reptile. But the internal metabolic change called for the production of an external alteration, for the hitherto naked or scaled skin of the pre-mammal permitted loss at the surface of the heat produced within. By one of those mysteriously controlled correlations which defy any such interpretation as that of chance variations the epidermis reacted, and fine epidermic outgrowths (hairs) were produced instead of, and probably as a derivative of, the original system of flattened protective thickenings (scales).

A hairy covering now became the distinction of the small and

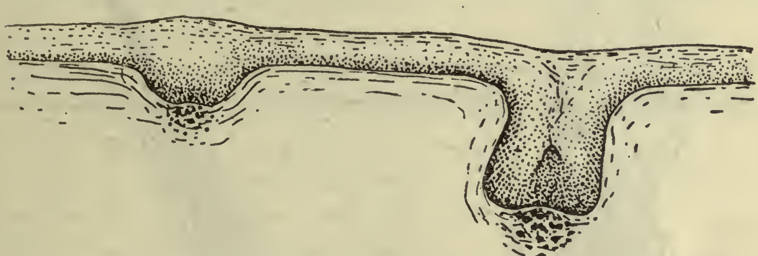

Fig. 56.—Two stages in the development of a hair. Stage 1, the proliferation of the epiblast. Stage 2, the formation of the hair papilla.

active animals from which the great group of mammalia was derived. All sorts of secondary uses are made of hair when once it has become a mammalian birthright, but this birthright is never bartered away, save when some other, and more appropriate, means is adopted for fulfilling its original *rôle* of preventing the surface loss of heat.

When, for some reason or other, hair upon the entire surface of the body becomes undesirable, then loss of heat by radiation may be prevented by the development of a protective layer beneath the skin, instead of upon its surface. Of such a nature is the deposit of blubber in aquatic mammals, such as whales, etc. This development of a peculiar subcutaneous stratum is of interest to the student of human anatomy. Did Man lose his body hair because he took to protecting himself with some form of artificial covering, such as the skins of other animals, or

various vegetable fabrics which compose articles of primitive clothing ? Did Man cover his nakedness and so lose his hairy pelt ? Clothes, in their inception, might conceivably be either for the purpose of adornment or for protection ; in their modern developments they subserve both functions. We know that they are not necessary to protection for a very large section of humanity, and we know, also, that in those people who go unclothed there is no noteworthy compensating development of body hair. Indeed, the exact contrary is the case with the negro races, for it is well known that far less body hair is developed in the unclothed negro than is present in the average clothed

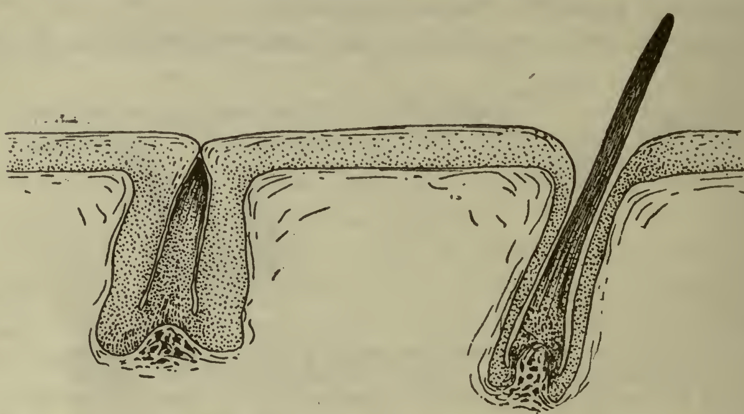

FIG. 57.—Two later stages in the development of a hair. Stage 3, the formation of the hair shaft. Stage 4, the eruption of the hair.

European. It would seem therefore that Man has developed some system of ensuring heat retention which renders a hairy covering unnecessary even in the absence of any compensating clothing. Without, perhaps, very consciously realising the fact, every medical student knows that this is indeed the case. All the difficulties of his first introduction to practical anatomy, which remain for ever a connotation of the term "superficial fascia," are the outcome of this human development of a subcutaneous barrier against heat loss. From the point of view of the taxidermist Man is one of the most unsatisfactory subjects, for few animals are so difficult to skin as Man, and it must have struck any one who has any experience of such things that the relation of the skin to the underlying tissues in all the monkeys

and apes is very different from the ordinary human condition. When a monkey is skinned it is only necessary to make an incision, and then to remove the skin from the subjacent muscles with a blunt instrument, or even by pulling and turning the skin inside out, as rabbits are commonly skinned. But the skinning of a man is a far more laborious process, for the intervention of a thick pad of fibrous tissue and fat between the skin and the muscles renders the removal of the skin, and nothing but the skin, a business of some difficulty. Exactly the same difficulty is experienced in cleanly skinning other naked skinned mammals and aquatic forms in which this layer, the homologue of the whale's blubber, is well developed. Man therefore has his own anatomical compensation for the loss of hair, and his clothes may be but little more than an æsthetic luxury. It is the development of this subcutaneous fat layer which gives the human form that rounded contour which is so different from anything seen in the monkeys and apes, and which we have come to think is essentially beautiful. The aged and skinny appearance of the monkey is, however, very nearly matched by the human fœtus before this fat layer is developed, and the fœtus of six months has a typically "old man" or even monkey aspect, which becomes lost in the later months when the subcutaneous fat is deposited.

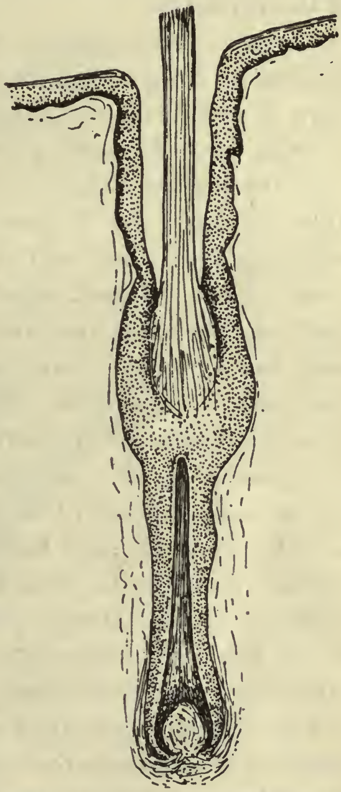

Fig. 58.—Section showing the replacement of an old hair by a new bud growing at the hair root. (Modified from Branca.)

The zoological expectation therefore would be that Man was specifically a relatively hairless animal, and that his body hair had not disappeared necessarily as a consequence of wearing

clothes. A scant hairy covering is typical of the chimpanzee among the anthropoids, and the very considerable exposure of a comparatively pale skin is one of the features which give a singularly human aspect to this creature, which is not, however, in several other anatomical details the most truly anthropoid of the Primates.

The hairy coat is disposed over the surface of the body in ordered fashion, by being arranged in definite tracts in which the hairs have a definite direction, and which are separated from neighbouring tracts by partings, whorls, or vortices. The hair tracts upon the general surface of the body do not concern us, but those upon the hand are of interest. As an animal moves forward, one border of its limb will be in advance of the other: there is a front edge and a back edge to each limb and a front edge and a back edge to hand and foot. In more precise language, each limb has a preaxial border and a postaxial border. We should naturally imagine that structure would best be arranged to subserve function if the hair were so disposed as to stream from the preaxial to the postaxial border. The preaxial border is the advancing aspect of the member, and any other arrangement would lead to the hair being rubbed up the wrong way as the animal progressed. Translated into the terms of human anatomy, one would expect that the hair on the fingers and hand would be directed from the thumb (preaxial digit) towards the little finger (postaxial digit).

This very simple state of affairs is commonly not appreciated, with the consequence that one may meet any day with the student who can tell with certainty if a pisiform bone belongs to the right side or the left, but who would be totally at a loss if asked to determine to which side a single amputated finger belonged.

The author regards knowledge as to the right or left-sidedness of individual carpal bones as a rather superfluous acquirement on the part of the student who is destined to heal the sick, and one that is retained in the memory only at the expense of some more really useful knowledge. It is a slur upon the trend of modern medical education that students should know the *details* of "siding" carpal bones and not realise the *principle* of determining to which side a whole finger belongs.

Hair is not uniformly distributed over the dorsal surface of the hand and digits; it is absent, as a rule, over the actual

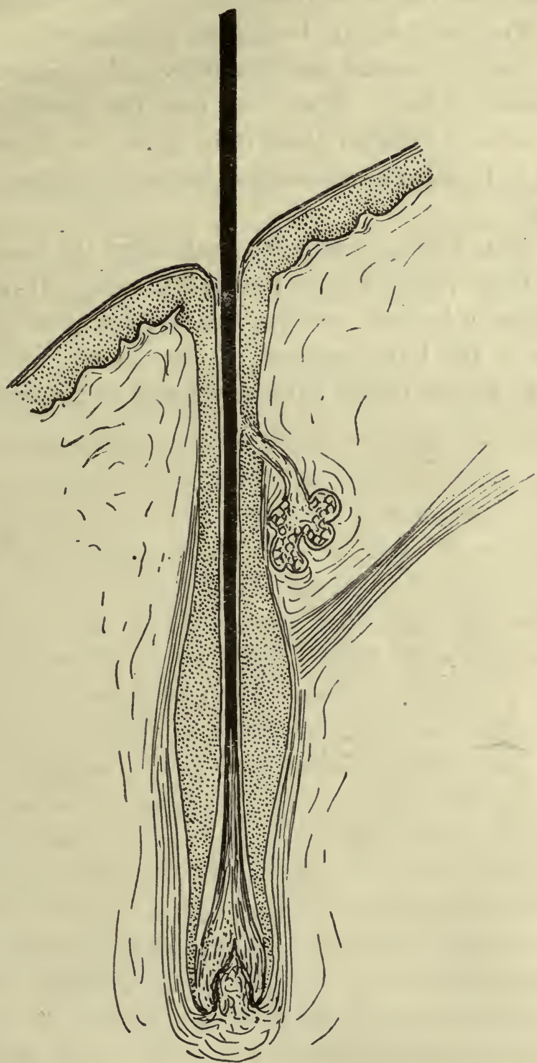

Fig. 59.—Section showing a perfect hair and the structures in connection with it. (Modified from Branca.)

knuckles, and grows more freely as tufts upon the dorsum of the phalanges. Upon the radial border of the hand the hair is more scant than it is upon the ulnar side, and the thumb is very often practically devoid of hair. The tuft upon the basal phalanx

is usually well marked, and it will be readily seen that the tips of the hairs composing these tufts point to the postaxial margin, towards the little finger, or towards the side to which the finger belongs. The tufts upon the medial phalanges are generally somewhat less developed, and the terminal phalanx is always totally devoid of hair. Upon the toes the growth of hair is generally more developed than it is upon the fingers, and its disposition is in all respects similar to that described as typical of the hand.

As with body hair generally, the hair upon the hands and feet is less well developed in women than it is in men. It ranks among the curiosities of human anatomy that a man practically always has hair upon the basal phalanx of the big toe, while this tuft is commonly absent or but little developed in a woman.

CHAPTER XI.

The Position of Rest.

In the mechanism of animal life it is a universal law that those periods of activity which are the typical display of the existence of life are followed by periods of rest. Activity presupposes rest as life presupposes death. We need to rest our brains, our digestive glands, our muscles, and all those agents by which the complex processes of life are carried on. For instance, in those animals in which the sense of sight obtains a representative area in the cortical grey matter of the brain it is necessary to shield the brain at intervals from the instreaming visual stimuli gathered from the retina of the eye. Visual stimuli must, in some way, be cut off from the retina, for only in this way will the visual area of the brain obtain rest.

The eyelids are the structures that fulfil the *rôle* of resting the brain from the rays of light which otherwise would create cortical pictures and maintain cerebral activity. If an animal has no eyelids, we may be sure that sight is not a cortical function, and that the animal " sees " only a very limited array of pictures, and is sensitive to them only in a purely reflex manner. But when sight becomes a cortically represented sense, when all things seen by the eye enter into the animal's consciousness, then eyelids become a necessity for screening the eye from the visual impulses, and so shielding the brain from visual impressions. The upper eyelid is held up by muscles, and when rest is needed, the muscle shares in the desire for repose, and the upper lid droops and the eye closes as the muscle relaxes into a position of rest. For the philosopher there has always been an attractive theme in the mechanism of the eyelids and the jaws, for whereas it is the upper eyelid that is held up by muscles, it is the lower jaw which is the mobile member and is supported by muscles. The eye is kept open and the mouth is kept closed by muscular effort. When rest is needed, and muscular relaxa-

tion takes place in sleep, the upper eyelid droops and closes the eye, whereas the lower jaw drops and opens the mouth. This simple fact has afforded food for reflection to many ; and, indeed, a bewildering picture is called to the mind when we attempt to imagine the condition which would be present were the muscular control of the eye and the mouth to have been arranged upon an opposite plan. But we need not be led into any such alluring by-path of speculation, for we will accept things as we find them and merely recognise in the shutting of the eye and the opening of the mouth the general principle that all parts which are under the control of muscles tend in movements of quiescence to assume a definite attitude of repose, which we will name the Position of Rest.

It is impossible to discuss this subject even in the cursory way in which it is here dealt with without a reference to two men : Hilton, of Guy's, and Ellis, of Gloucester. Hilton's lecture on Rest and Pain, originally delivered during 1860 and the two following years, should be read by every medical student once at least during his study of anatomy, once again during his practical work in the wards, and afterwards as often as possible during his career as a medical practitioner. The work of Ellis, which marks a period some twenty years after Hilton had delivered his lectures, might have been penned with a prophetic insight into the needs of surgical knowledge during the War. It may be said by the medical historian of the future that in dealing with the problems of war surgery we had a distinct asset in that our surgeons were familiar with the doctrines associated with the names of these two Englishmen. Never has the knowledge of the position of rest, the need of rest, and the meaning of pain been more demanded of the surgeon, and never has the judicious use of this knowledge been attended by greater benefit in the relief of the injured man. It might also be added, as a corollary to this, that a lack of appreciation of the doctrines of Hilton and Ellis has never had so large a field in which to display the disastrous effects of enforcing rest by the too prolonged immobilisation of injured parts or by the immobilisation of parts in incorrect positions. If it becomes necessary to keep a hand at rest, two things must certainly be kept in mind,

and the first is that immobilisation of an adult hand which has suffered any injury to its nerve supply is a risky thing, and such a hand must be kept under observation with the greatest care, since intractable stiffness of the joints will inevitably result from any neglect. The second is that, dealing even with a normal and uninjured hand, immobilisation should only take place in the position of rest. A hand is not in a position of rest when it is fixed flattened on to a splint with flexors stretched and palm flattened, nor is it in a position of rest when it is fixed doubled up into a fist with flexors relaxed but extensors on the stretch. No rest is attainable at any time in any position in which any group of muscles is put under a tension to which these muscles do not attain in a normal resting position. To determine the position of rest we must do as Ellis did, and watch the part when relaxed in sleep, when nerve control is temporarily in abeyance and when the real "postural tone" of the muscles alone is exerting itself. Then we shall see that the forearm is held somewhat pronated, that the wrist is flexed, the palm of the hand hollowed, and the digits bent in towards the palm in varying degree. The little finger is the most bent: it is flexed at the metacarpo-phalangeal joint and at both interphalangeal joints, and its tip is usually deviated somewhat towards the radial border of the hand. Annularis shows the next degree of flexion: the bending takes place at the three joints, its tip being bent almost directly forward. Medius is not quite so acutely flexed as is annularis, and its tip points distinctly towards the ulnar border. The flexion of these three ulnar-sided digits brings into prominence the distal transverse palmar crease, which is the folding line produced in the normal hand by their common flexion. The index finger is flexed to a distinctly lesser degree: the terminal interphalangeal joint is bent but little, and the metacarpal phalangeal joint remains more extended than is the case with its neighbours. The finger is kept aloof from the common transverse flexure of the palm, and its tip is very definitely deflected to the ulnar margin. The thumb is held midway between flexion and extension, and it is slightly adducted and opposed, so that the palm is made hollow from side to side as well as in its length. This is the position in which the hand

should be placed if it becomes necessary to render it passive for any length of time. The ideal splint must therefore be one in which this position is permitted, and the ideal splint must also be arranged so that every joint of the hand may be moved in order to prevent joint stiffness. The relative extension of the index finger when the hand assumes the position of rest is a noteworthy character, and it is one in which some variation is displayed. There are people who flex all the fingers to an almost equal degree when the hand is passive, but it will be noticed that in these people the distal transverse palmar crease line tends to assume the simian form, and run straight from ulnar to radial border of the palm. This is therefore not the typical human position of rest. One rather curious variation of the normal resting position may be recorded, since it does not appear to be at all uncommon, and, in some cases at least, it runs in families. In this pose the tip of the thumb is inserted between the relatively extended index finger and the more flexed middle finger, and it is held thus with its terminal phalanx protruding among the knuckles of the proximal interphalangeal joints.

The normal position of rest is the expression of a state of rest of muscles, joints, nerves, and vessels in the passive part, and it is determined and maintained by the postural or resting tone of the muscles. The flexor muscles and the extensors, which are their antagonists, have a normal length and a normal elasticity, and when they cease to exert their pull of an active contraction on the bones they assume a definite resting phase, producing a definite posture of the part which may be altered by the active contraction of members of either group.

Now, since the normal position of rest depends upon the normal postural tone of the muscles which act upon the part, it is easy to understand that an alteration of the postural tone of the muscles might well lead to an alteration of the position of rest. We could conceive of states in which, with the relaxation of sleep, the hand would not fall into its normal position of rest, but might take up some other position in which maybe undue extension or undue flexion of the parts constituted a well-marked departure from the normal. Such is the case in many conditions of disease of the nervous system, when the abnormal

over-action of one group of muscles leads to a contracture of the hand which persists when the patient is asleep and even when he is under the influence of an anæsthetic. In such a case the postural tone of the muscles is definitely altered by the abnormal condition of the nervous system. But suppose a person either consciously or sub-consciously mimics such a condition, and holds the hand in the abnormal position during his waking hours, the normal postural tone of the muscles will nevertheless reassert itself during the relaxation of sleep or anæsthesia, and the hand will fall flexed into its normal position of rest. In this way we may differentiate between contractures due to disease and certain contractures due either to hysterical conditions or to definite conscious imitation of diseased states. But caution is necessary in the application of this method of diagnosis to all the curious displays of that manifestation of nervous activity which is termed hysterical. If a curious and abnormal position of the hand (or of any other part of the body) be maintained for a sufficiently long time, it matters not what may be the cause of the adoption of the position, the postural tone of the muscles will undergo a change in response to the new demands of the long-maintained posture. The postural tone of the muscles will in time accommodate itself to the new condition, and an abnormal position of rest will

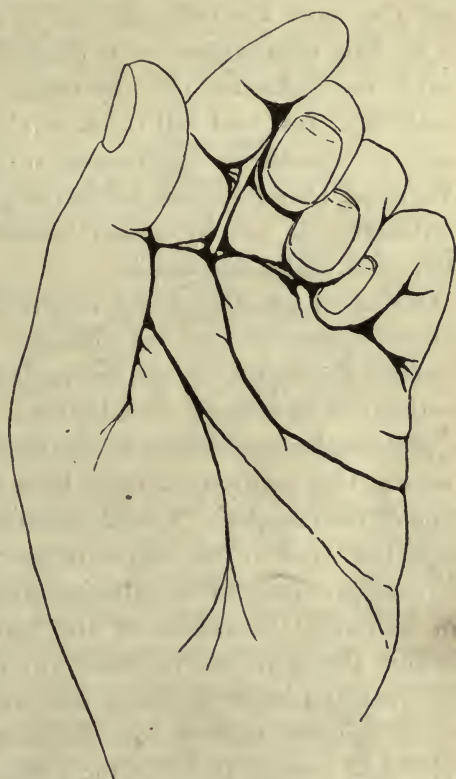

Fig. 60.—Palmar view of the left hand illustrating the position of rest.

certainly result. In this way contractures which are, without the least doubt, hysterical in their origin and in their maintenance, will persist during sleep and under anæsthesia as certainly as will contractures which are due to real organic disease.

We have a normal position of rest for the hand depending upon the normal postural tone of the muscles acting on the hand, but if we alter the postural tone of the muscles by real disease or by long continuance of a position adopted and maintained under the influence of "hysteria," we shall surely alter the position of rest and fail to show the normal condition though sleep or anæsthesia deprives us of our working consciousness. We must therefore not be too dogmatic in asserting that a contracture is not hysterical because it is maintained during sleep and under anæsthesia.

One other practical point results from this alteration of the normal postural tone of muscles. Some manifestations of hysteria are rapidly—even dramatically—cured when the proper methods of treatment are adopted; but obviously we must not expect sudden cures when we are dealing with hysterical contractures so long maintained as to have altered the normal postural tone of the muscles. A sudden return to the normal cannot be expected even if the cause of the condition may have been successfully dealt with. Having good reasons for believing that an abnormal condition of the hand was due to hysteria, we should, therefore, not be shaken by finding that the contracture was maintained during sleep and under anæsthesia, nor should we be tempted to revise our diagnosis because the condition did not yield immediately to the methods successful in eradicating certain hysterical manifestations. Not till by re-education we have restored the natural postural tone of the muscles can we hope to see the abnormal changed to the normal, and the diagnosis vindicated.

That the position of rest denotes a phase of nerve rest is at once shown if we compare the hand of a sleeping person with the hands of a series of patients suffering from division of the individual nerves of the hand.

We may say that the position of rest is a picture of the resultant

of the inaction of all the nerves supplying muscles acting upon the hand. The position of rest is a composite picture of ulnar, median, and musculo-spiral paresis. The approximation of the fingers and the flexion of the minimus and annularis evince the abeyance of ulnar stimuli, the position of medius and index is indicative of median inaction, and the drop-wrist and the poise of the forearm are tokens of musculo-spiral inactivity.

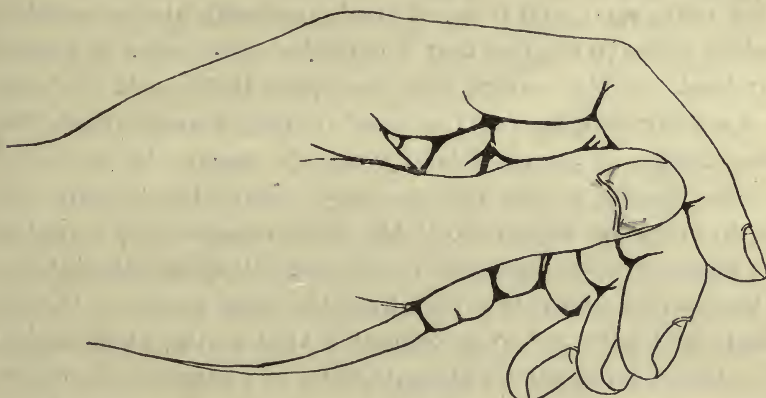

FIG. 61.—Lateral view of the left hand illustrating the position of rest.

The position of rest is a resultant of nerve rest. Although this is generally recognised in the case of the hand, it is not always appreciated that the condition of "drop-foot" is merely the position of rest of the foot, and that every one rests with the feet in the position which expresses paralysis of the anterior tibial nerve, a position which may be aggravated by the pressure of the bedclothes when the patient lies on his back in bed.

That the position of rest indicates joint rest needs no lengthy discussion, since it is from the point of view of the joint that the resting position of limbs has generally been studied by the clinician. Hilton's great work was directed towards explaining the position into which joints fell when inflammatory conditions were present and when rest was demanded for the inflamed joint surfaces. Of the hand he says: "Who ever saw a finger with an inflamed joint of any duration in which the finger was perfectly straight? Such a thing was never seen; the inflamed joint is always more or less bent." He also notes the fact that "the

forefinger when inflamed is generally not so much flexed as the others," and that the thumb "is not so much flexed towards the palm when inflamed as the middle and ring fingers" (p. 175).

That rest of muscle, nerve, and joint was secured by a physiological co-ordination Hilton recognised, and he summed up this co-ordination in the dictum which is generally known as Hilton's Law. Hilton's Law is not so familiar to students of the present generation as it was, and well deserved to be, to those of only a few years ago; and it is not at all impossible that its modern neglect is due to the fact that it is hardly ever quoted in current text-books in the correct form in which Hilton laid it down. As it appears in Hilton's "Lectures" (p. 168), it asserts that "the same trunks of nerves whose branches supply the groups of muscles moving a joint furnish also a distribution of nerves to the skin over the insertions of the same muscles, and—what at this moment more especially merits our attention—the interior of the joint receives its nerves from the same source." Nerve, muscle, and joint are so co-ordinated that in the physiological abeyance of nerve stimuli all parts share in a harmonised posture of repose.

But in the resting part there are also vascular channels, and these too share in the general condition of comparative functional repose. The venous system of the limbs is so disposed that the rapid return of blood to the heart is brought about by contractions of the muscles in the limbs. Where muscles are gathered together into groups which act upon a segment of the limb, some of the venous channels always run between the muscle layers; and when the muscles contract, blood contained in these vessels is squeezed just as a sponge is squeezed with the hand. The blood is gathered together from the intramuscular channels of one muscle group by passing along valved veins which open again into the intramuscular venous meshwork of the group of muscles next above it in the limb. In this way venous blood is squeezed from muscle group to muscle group along a limb, and the blood which is poured into the limb through the arteries is rapidly returned to the heart. But when the muscle groups cease to contract in repose this syringe-like action comes to an end, and the circulation of the limbs becomes

slowed, blood tends to gravitate into the intramuscular veins, and the work of the heart is reduced. The position of rest is the position which permits of the venous system of the limb containing a maximum of blood, and so it allows for the greatest degree of stasis of the limb circulation, and cardiac rest. Before full activity is regained this blood must be returned from the limbs to the heart in order to permit the full volume of blood being circulated to the brain and lungs. It is for this reason that when waking and passing from the position of rest to a state of full activity we "stretch" our limbs. In the act of "stretching" we place the limbs in a position which is the exact opposite to the position of rest, we assume a pose in which the limb vessels are capable of holding the minimum quantity of blood, and we contract our muscle groups in order to drive the blood inwards towards the heart and brain. Stretching is often accompanied by yawning, and this physiological act is merely an expression of the stagnation of blood in the abdominal vessels, from which it must be forced back to the heart by the downward piston stroke of the diaphragm. There is much to be said for the Eastern belief that no one should be roused suddenly from slumber, but the belief is justified rather by the reason that one should have time to stretch and yawn, and so supply the brain with blood, than by the supposition that the spirit engaged, maybe, in some far-off dream adventure, may not have time for return. It is noteworthy that animals which do not sleep in a relaxed position, or which even sleep standing up, as do many of the Ungulates, do not stretch or yawn.

CHAPTER XII.

The Fascias.

No portion of the animal body has suffered so much at the hands of the descriptive anatomist as have those lowly tissues classed together as fascia. Whatever strides in the study of anatomy may be attributed to the introduction of formalin as a hardening and preservative reagent for anatomical material, it cannot be claimed that our conceptions, or our descriptions, of the arrangement of fascias have been made particularly clear by modern methods of practical anatomy. For the medical student the study of the fascias of the body presents one of the most bewildering problems, and this is so partly because this tissue has remained undescribed in the types of lower animals he has dissected, and partly because in human anatomy the fascias are apt to be described without regard to their real significance and function. And yet fascia is of much interest for its own sake, and for the purpose of practical medicine and surgery few tissues so well repay the study devoted to them in practical anatomy.

Fascias may be described as tissues of low organisation which remain undifferentiated when other structures acquire their definite specialisations. Thus, when the muscles are developed in the embryonic limb they are differentiated in the midst of a mass of tissue, some of which remains undifferentiated around each specialised muscle mass. In this way a certain amount of tissue of low specialisation is left between the specialised fibres of each individual muscle, around each separate muscle, and around each group of muscles. As this tissue occupies these different stations in the adult body, it is given a host of different names. Thus, confining our attention solely to the example we have taken, the tissue between each of the muscle fibres is known as the *endomysium*, that between the collected groups of fibres as *perimysium*, and that around the whole

muscle as *epimysium*. The epimysium is also known in gross anatomy as the sheath of the muscle, and when encountered in its extended form as the tissue spreading over whole groups of muscles it is termed *deep fascia*. Fascia therefore may be regarded as tissue left over between the more specialised differentiated tissues, and so may be said to form the packing material of the animal body. Now the amount of the packing material that is present in any part of the body will obviously depend upon the disposition of the neighbouring differentiated structures. Where structures and organs are tightly packed, the intervening packing material will be sparse in amount, and will exist only as sheaths or as fibrous tissue planes. It is in this way that the fascias are arranged, for the most part, in the limbs. But where the organs are loosely packed, to allow of their expansion and contraction in a hollow cavity of the body, the packing material will be abundant, and it will exist as loose strands of tissue occupying spaces between the neighbouring organs. There are, therefore, fascial planes and fascial spaces. Both are important, since exudates or extravasated fluids may track along fascial planes or gravitate into fascial spaces.

Confining our attention to the hand, the deep fascias are present as the sheaths of, or as the packing which wraps around, all the differentiated tissues met with. Although in practical anatomy it is customary to describe as deep fascia only the general investment of the muscle masses, this general investment cannot properly be considered apart from all the septa which dip down from it to intervene between all the deeper structures. Thus the fibrous tissue sheaths of all the muscles, tendons, nerves, vessels, bones, and joints, as well as the general investment of the whole mass of these structures, must be studied as an entity. The functions of these sheaths are varied in accordance with the specialisation of the structures which they surround, but in general two simple *rôles* are fulfilled by all fascial investments. In the first place, the blood-vessels, lymphatics, and nerves which run to supply an organ are carried to it along the planes of fascia which separate it from neighbouring structures. The fascial planes are the great highways of the body for the passage of vessels and nerves. In the second place, the fascial

planes permit of movement of one structure upon another, and this is an extremely important function, which is apt to be lost sight of in that descriptive anatomy which is written as the outcome of the study of formalin-hardened material. As a general rule, all structures in the animal body which are subject to movement are invested with a definite fibrous sheath, and one may say, in general terms, that the greater the mobility of the part, the more perfect will be the development of the sheath. One has only to contrast the capsule of the parotid gland, which is moved with every action of the jaw, with the condition present in the relatively immobile pancreas.

It is the presence of the fascial investments which gives that wonderful slipperiness to structures which, so real in the living body, is lost entirely in preserved material. By reason of these gliding planes of fascia structures may move apart when even very slight pressure is applied to the skin which lies over them. This is particularly well exemplified in the neck, where the fascial planes constitute a system the description of which has become a test of the student's memory, but which finds its clear functional expression in the truly marvellous manner in which structures will slip out of the way and dodge the suicide's razor, the unwary surgeon's knife, or even the passage of a high velocity bullet. This very simple function of fascias is not made sufficiently clear from a study of the cadaver; but nevertheless it is a very important, even life-saving one, since it is the expression of a mechanism whereby pressure on the skin overlying a structure at once causes the structure to dodge aside from the point of pressure and escape from a penetrating injury. During the war missiles of all sorts have, in cases without number, traversed portions of the body without injuring structures which lay anatomically directly in their path between entrance and exit. It is this mobility conferred on structures by virtue of the gliding planes of fascia that has permitted these things to happen. Were our anatomical knowledge based merely upon the findings of the dissecting room, these apparently miraculous escapes of nerves, vessels, etc., would be deemed impossible, and the anatomist may be said to owe an apology to fascia, since hitherto he has been apt to assess the whole value of this

despised material merely as fibrous tissue which forms planes for the tracking of pus.

In addition to forming planes, and permitting of mobility, fascia gives rise to definite retention bonds where need for these structures arises. It may be that in some particular movement of a part some structure is liable to be displaced from its proper position. When this condition is found anywhere in the body we may be certain that some portion of the fascia will be specially developed to restrain the structure and prevent its unwonted displacement. This specialisation is usually developed in connection with the play of tendons, and it will be studied later on in connection with them, but here we might instance the very special way in which structures other than tendons—for instance, the ulnar nerve behind the elbow—are held in place by fascia. Fascia may make pulleys, slings, or tunnels for the play of tendons; it may make supports, bonds, and bridges along which vessels and nerves may pass; and it may form definite compartments in the body, so that movement may be carried on in one compartment without disturbing the contents of other compartments. All these conditions are displayed in the anatomy of the hand.

Apart altogether from forming the sheaths of separate structures, the deep fascia forms a general investment for all the structures of a member. Thus the muscles, etc., of the arm, forearm, and hand are all enclosed in a general sleeve of deep fascia which wraps around all the structures and holds them in place. This ensheathing layer for the whole limb constitutes the deep fascia as it is generally recognised in descriptive anatomy. The ensheathing deep fascia does far more than merely hold in place all the structures which compose the total anatomy of the limb, for its great physiological *rôle* may be likened to that of an elastic stocking. More attention will be paid later on to the condition of circulation in the limbs, but without any further discussion it may be accepted as obvious that the fluids of the body will tend to gravitate passively into dependent parts. The muscles are the great reservoirs of blood when the limbs are passive, and, therefore, around all the distensible muscles a firm sleeve of fascia is placed to resist the passive gravitation of

fluids. Deep fascial investments of the limbs are present largely to resist passive fluid pressure. Evidence of this will readily come to the mind of every medical student, for he will recall how much thicker and firmer is the investing fascia in the leg than in the arm, and he will realise that here is the explanation of the fact that, whereas the deep fascial investment of the upper portions of the limbs is not sufficiently thick to be an impediment to good dissection, in the lower segments of the limbs the separation of this thick investment from the underlying muscles is a matter of great difficulty. The more dependent the part in the ordinary position of the body, the thicker and more complete is the elastic stocking of deep fascia.

Different altogether from the deep fascia is the so-called *superficial* fascia to which we have made previous reference in dealing with the crease lines of the palm. Superficial fascia is merely the fat-containing subcutaneous tissue which, preventing heat loss from the naked surface of the skin, is present as a padding of varying thickness all over the body. It is in the superficial fascia that nerves and vessels, destined for the supply of the skin, ramify on their passage to the surface. It is a general rule that nerves and vessels pierce the deep fascia as single trunks at discrete openings, and that subdivision into branches takes place in the subcutaneous layer. If a superficial vein has to pierce the deep fascia to reach the deeper venous connections, it is the rule that its superficial tributaries join it before it passes through the deep fascia ; and when an artery or a nerve sends multiple twigs to supply an area of skin, it is the rule that it breaks up into its twigs only after it has pierced the deep fascia. It is this arrangement which makes the student's first introduction to practical anatomy so exceedingly trying, for he is set to work to find in a particularly difficult tissue the fine terminal branches of structures the trunks of which he has not yet seen.

Superficial fascia constitutes the gliding plane which imparts mobility to the skin, as deep fascia permits mobility to the deeper tissues. When superficial fascia is abundant and lax, the skin may be freely pulled up and slid about upon the deeper tissues. As a general rule, the superficial fascia is more lax

upon the ventral surface of the body than upon the back, and upon the flexor surface of the limbs than upon the extensor surface. In some persons this mobility is permitted to a more

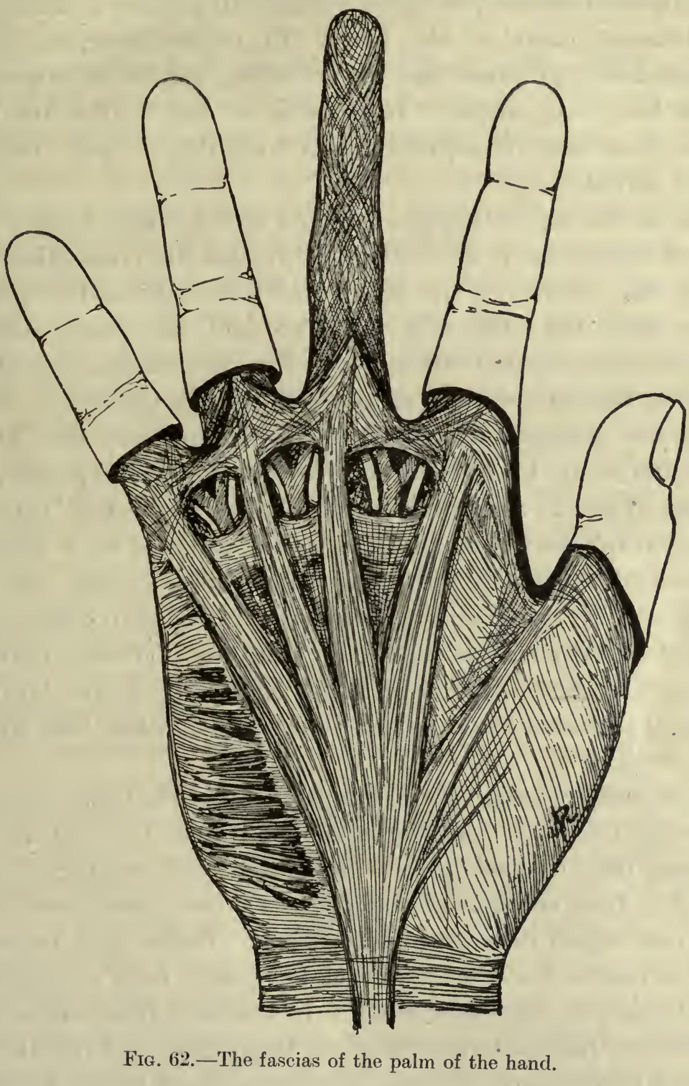

FIG. 62.—The fascias of the palm of the hand.

than ordinary extent; and then, and doubtless after some additional artificial cultivation, the " elastic-skinned man " becomes a possibility. In an extreme example of this condition (such as in the case of one Tom Morris) the skin of the chest could be

pulled up over the face. It is owing to the normal differences in the structure of the superficial fascia, leading to a varying degree of fixity of the skin, that the products of inflammation developed in the deeper layers of the skin behave so differently in different parts of the body. In dense superficial fascia inflammatory products may be localised, but in lax superficial fascia they may spread. In this way a " boil " upon the back of the neck may be expressed as a " cellulitis " upon the front of the throat.

The anchoring of the skin by septa of superficial fascia to the deeper structures we have already examined in connection with those skin joints of the hand which constitute the palmar crease lines, but these skin joints are only the grand manifestations of the normal bonds which superficial fascia constitutes between the skin and the deep fascia all over the body. These bonds are arranged in a definite manner in every part of the skin, and they have been studied extensively—especially by Langer (1861–2) and Hoffman (1881)—in connection with the direction in which a simple skin wound inflicted by a rounded instrument tends to be elongated. These bonds are not sufficiently strong to produce stasis points and skin joints under normal conditions, but in old age the loss of elastic tissue in the texture of the superficial fascia and in the deeper layers of the skin produces those numerous additional stasis lines known as " wrinkles."

There still remains another source of fibrous tissue which is classified under the generic name of fascia, for just as the ordinary deep fascia is tissue which has never been differentiated into any more specialised structure, so a once specialised structure may again degenerate into fascia. Fascia may represent the last traces of a structure which has passed from phylogenetic senility into phylogenetic death. In this way there are present in the body fascias derived from the degeneration of functionless muscles, and from the tendons of muscles. Such fascias generally tell of their origin by definite peculiarities of their texture, for they are strongly fibrous, their fibres are arranged in a regular manner, and the tissues are not woven by strands running in diverse directions. As a rule, such fascias are shining, and often

the fibres present a beautiful pearly sheen of bluish or greenish iridescence.

The *superficial fascia* of the hand needs no further description, since its outstanding peculiarities have been mentioned in dealing with the crease lines.

The *deep fascia* forms a general dense ensheathing envelope for all the muscles and tendons of the hand. It is specialised in certain places to form definite named ligaments. It is also continued as partitions among the deeper structures, forming sheaths of muscles and tendons. Finally, it is joined by the degenerated tendon of the palmaris longus muscle. The ensheathing layer forms a complete investment for all the structures composing the whole anatomy of the hand, and it covers the back and front of the hand alike, constituting a perfect fibrous glove beneath the superficial fascia. Most of the strands of the fibrous glove run round the hand and fingers, but in all places, and upon the fingers especially, the texture of the fabric is woven by strands running in different directions. At the wrist, across the heads of the metacarpal bones, and in the thickness of the webs of the fingers the transverse fibres are especially thickened. The thickenings at the wrist are especially designed to keep the tendons in place, and under the name of the annular ligaments will be referred to in more detail in dealing with the tendons.

The transverse strengthening across the heads of the metacarpal bones is the deep fascial expression of the stasis point to which the skin is tethered in flexion of the metacarpo-phalangeal joints, and it may be regarded as the deep attachment of the moorings of the transverse palmar crease lines. This portion of the deep fascia has been named the *superficial transverse palmar ligament.* The transverse fibres of the web are developed especially for the support of this free skin fold, and they have been named the *ligamentum natatorium* (Grapow), since they are specially developed in those animals in which the web of the digits is specialised as a swimming organ. In human anatomy they are generally known as the *interdigital ligaments.* From the web of the fingers this flange of fascia is continued along the sides of each digit as a fibrous septum which joins the skin to

the fascia over the sides of the phalanges and interphalangeal joints. Upon these little lateral flanges the vessels and nerves of the fingers run, and they are generally known as the *cutaneous ligaments of the phalanges*, or as *Cleland's skin ligaments*, from their describer (*Jour. Anat. and Phys.*, Vol. XII., p. 526). The interdigital ligaments and their continuations along the fingers as the skin ligaments exert some restraining influence upon the movements of the fingers. In their normal development they hamper the full flexion of a single finger when its neighbours are extended; in their abnormal development they may very considerably lessen the free play of individual digits. They are especially brought into evidence in those cases where, as the result of some injury, a finger becomes permanently bent, for then the neighbouring fingers tend to be dragged down also, and one bent finger commonly entails the flexion of its next-door neighbour. Upon the back of the hand and fingers there are no portions of the ensheathing layer of deep fascia so specialised as to have received definite names in descriptive anatomy.

Of the deep ramifications of the fascia we need note only those which are of sufficient importance to have special names allotted to them. As the muscles of the thumb and of the little finger constitute two well-defined groups which act on these two digits alone, and are independent of the muscles which act upon the rest of the digits, they are separately wrapped in fascial envelopes. In this way two septa may be defined separating the thenar and hypothenar muscles respectively from the central compartment of the hand. These septa are named the *internal and external intermuscular septa*, and they pass to the ventral surface of the metacarpal bones of minimus and medius, dividing the palm of the hand into three separate ventral compartments (see Fig. 63). The deep wall of these compartments is constituted by the metacarpal bones and by the fascia that passes across their ventral surfaces. This deep palmar fascia is sometimes named the *anterior interosseous fascia*, a similar layer, the *posterior interosseous fascia*, existing across the backs of the metacarpals. As the anterior interosseous fascia is traced towards the heads of the metacarpal bones it becomes especially thickened, forming a ligament which is known as the *transverse metacarpal ligament.*

This specialised band of fascia passes from the metacarpo-phalangeal joint of the little finger to that of the index, but it is not continued on to the mobile metacarpal of the thumb. In the foot there is a corresponding ligament, but here it is continued right across the sole and is fixed to the metatarso-phalangeal joint of the staple big toe.

No other continuation of deep fascia need detain us here, and it remains only to call attention to those radiate longitudinal fibres which are known as the *central portion* of the palmar fascia, and which are usually alone referred to when the surgeon speaks of the palmar fascia. These fibres are in obvious continuity with the attenuated tendon of the palmaris longus muscle, and they have an exceedingly interesting history. The

FIG. 63.—The fascial compartments of the hand as seen in transverse section.

palmaris longus is a primitive muscle. In its fully developed functional condition it is the most superficial of the long finger flexors, and its purpose is to bend the fingers at the metacarpo-phalangeal joints. Three muscles compose the full series of long digital flexors: the palmaris longus, the most superficial, which flexes the metacarpo-phalangeal joints; the flexor sublimis digitorum, constituting an intermediate layer, which bends the proximal interphalangeal joints; and the flexor profundus digitorum, the deepest stratum, which bends the distal interphalangeal joints. In Man the flexores sublimis and profundus are retained in full functional form, and the palmaris longus exists in ninety out of every hundred persons, but its function of flexing the metacarpo-phalangeal joints has been taken over by other muscles. Its degenerated tendons are now represented

by a tendinous fascia which spreads out fan-like in the palm, but still divides into five distinct slips, one slip running to the base of each digit. In a very large number of animals the degeneration of this superficial flexor has proceeded further, for not only have its tendons been reduced to fascia, but the muscle itself has disappeared in the course of evolution. It is of interest to note that in the reduction of this primitive muscle the anthropoid apes have gone further than Man, for while the Gibbons and the Orang-utan commonly retain a palmaris longus, the Chimpanzee shows its presence less frequently, and only one Gorilla in every four presents any trace of its existence. Although in the foot a well-developed plantar fascia is present, the muscle from which the degenerated tendons are derived has disappeared altogether; it has probably become incorporated in the calf muscle known as the gastrocnemius and so lost as a muscular entity. To this subject we will return when treating of the muscles, but here it may be said that the usual teaching that the plantaris of the leg is the homologue of the palmaris of the forearm is probably incorrect. The derivation of the superficial longitudinal fibres of the palmar fascia from the tendon of the palmaris longus was first made clear by Dupuytren in 1832, and from a practical point of view the whole interest of these obsolete tendons is associated with his name. An insidious thickening and contraction of these fascial bonds, which produce a puckering of the tissues of the palm and an obstinate flexion of the fingers, is known as *Dupuytren's contracture*, and affords one of the many examples of pathological processes occurring in degenerated structures.

In the palmar fascia, upon the ulnar side of the hand, are somewhat variable muscular fibres, which run at right angles to the long axis of the hand, and are mostly inserted into the deep surface of the skin over the ulnar border of the hand. These muscular fibres produce a puckering of the skin when they contract, and when well developed they are capable of producing a long depression in the skin running from the base of the little finger to the wrist. This muscle—the palmaris brevis—has several distinctions. It is a muscle which has no homologue in the human foot, for the plantar fascia is devoid of any represen-

tative of these palmar fibres. It is an example of a muscle which is inserted directly into skin; and, therefore, like some occasional fibres of the facial muscles, it produces "dimples" when it contracts. It is a muscle which appears to produce an action which has but little cortical representation, and is therefore one which it is not easy to activate by a volition. Most people have a difficulty in "willing" that the palmar skin upon the ulnar side shall be puckered, and though the muscle may be well developed, it is difficult to produce a contraction by any voluntary effort. Nevertheless this voluntary power may be increased by practice. Probably as a corollary of this, it is a muscle which is particularly easy to stimulate directly or reflexly. If pressure is made with a finger-nail upon the wrist above the pisiform bone, it will be noticed that in most people the skin of the ulnar side of the hand is indrawn. This has been taken to indicate direct stimulation of the ulnar nerve, which is the nerve of supply to the palmaris brevis. But it is equally easy to evoke contractions of this muscle by pressing with the nail upon the pisiform itself, upon the base of the little finger, or upon the skin over various bony prominences of the hand, and it is therefore obvious that the contractions are produced, not by any stimulation of its nerve of supply, but by reflexes from the palmar skin. The meaning of this reflex awaits solution. Again, from the point of view of comparative anatomy the muscle is of great interest, for it is absent in all monkeys and anthropoid apes, although it is very constant in Man. What purpose it serves is by no means clearly understood. It has been said to be of use in deepening the hollow of the hand, as when water is drunk from the palm, or, as the older anatomists would have put it, to form the "cup of Diogenes," and it has been said (Henle) to protect the ulnar artery and nerve, which pass beneath it, by slackening the palmar fascia when some object is grasped firmly in the hand. Its action upon stimulation of the palmar skin has every appearance of being a protective mechanism, and it has been suggested that it is associated with the fact that Man has a habit of hammering or thumping with the ulnar margin of his hand, but what may be the exact meaning of this reflex is difficult to see. Its purpose is made less

easy to understand when we consider the fact that some Marsupials and some Lemurs possess a muscle which appears to be the homologue of our palmaris brevis. On the whole, it must be owned that, although the palmaris brevis is a human distinction when Man is compared with the monkeys or anthropoid apes, its utility is not very apparent to its possessors. It is possible that here again we have lingering in Man an extremely primitive muscle which has long since been lost in all those animals so often regarded as his phylogenetic forebears.

CHAPTER XIII.

THE JOINTS.

WHEN the first cell condensations, which are the precursors of the future bones, take place in the developing limbs of the embryo, they consist of massed elements of undifferentiated mesoblast, which is the simple embryonic tissue from which the bones, the muscles, the vessels, and the fascias are formed. At first, this axial condensation presents the same undifferentiated characters throughout the whole of its length in the limb bud; but later on changes occur in certain portions of its length: the simple mesoblast cells become differentiated in definite sites, and take on the characters of cartilage, the precursor of the adult bones. In this way a series of short rods of cartilage is developed in the midst of the limb, and around each rod, and between the ends of the rods, there persists the simple tissue from which they were specialised. The mesoblast which remains between the ends of neighbouring cartilages marks the site of the future joint, and the fate of this tissue depends entirely upon the demands which the functional use of the part will make upon it. If free movement is not desired, but resilience is necessary, the intervening mesoblast may become differentiated into cartilage, and then in the adult condition a wad of cartilage will separate two neighbouring bones. This type of articulation is called a *synchondrosis*, and in old age, or when rigidity is no disability, the intervening cartilage may develop into bone, and bone become cemented to bone in a *synostosis*. Again, when only limited mobility is required, but a certain amount of elasticity is essential, then the intervening tissue may develop into specialised fibrous tissue, and the resulting joint is known as a *syndesmosis*. In the hand we do not meet with any joints which conform to these types, for here the greatest freedom of movement is demanded of every constituent bone. When a free range of movement is required in

the adult joint a retrogressive change takes place in the intervening mass of mesoblast, for it ceases to exist as a continuous cell mass, and a space—the joint cavity—separates the two neighbouring bones, the original mesoblast forming the thin synovial membrane from which the lubricating synovial fluid is secreted. This type of joint is known as a *diarthrosis,* and all the joints of the hand are of this variety.

The undifferentiated mesoblast which wrapped around the

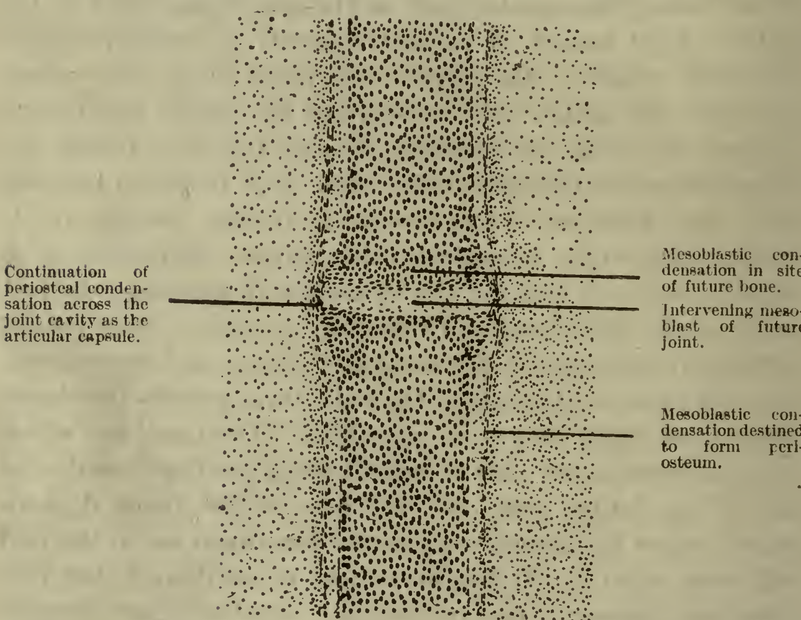

FIG. 64.—Diagrammatic representation of the mesoblastic condensations in a developing limb at the site of a future joint.

developing cartilages becomes the *periosteum* of the adult bones, and in the intervals between the bones it passes over the intervening tissue, and its altered adult representative, as a tough layer of fibrous tissue which is known as the *capsule of the joint.* This enveloping layer, formed from the undifferentiated tissue surrounding the primary condensations in the axis of the limb, constitutes a complete and continuous sleeve-like investment for the adult bones and joints; it may be regarded as a specialised portion of the deep fascia which is called periosteum around the bones, and capsule around the joints. The great

function of the periosteum is that it covers and protects the bones, and serves as the medium in which the blood-vessels ramify for the supply of the growing bone. A bone deprived of its periosteum is a bone deprived of its blood supply, and the source of its mineral constituents. The continuation of the periosteum as the capsule of the joint constitutes the bond between the two bones, and serves as a confining wall to the synovial space.

Fig. 65. — Diagram to show the relation of periosteum, capsule and articular cartilage in a simple diarthrodial joint.

In studying any diarthrodial joint attention has, therefore, to be paid to the articulating surfaces of the bones entering into the joint, to the intervening cavity of the joint, and to the capsule of the joint. In a joint of ideal simplicity the two engaging bones do not ossify down to their articulating ends, and the cartilaginous extremities of the two bones play upon each other through the intervention of a synovial cavity. The periosteum which ensheathes the bones passes from bone to bone across the joint as a simple sleeve of fibrous tissue, lined by the synovial membrane, and surrounding the cavity and enclosing the synovial fluid. Such a condition of simplicity is practically realised in the articulation of the ventral extremities of the ribs with the sternum, and it is departed from but little in the joints of the carpus. But in most joints modifications of this simplicity affect either the articulating ends of the bones, the cavity of the joint, or the capsule. In the first place, the capsule may not be uniformly thick upon all aspects of the joint. Some special stress, when the joint is in one particular position, may develop one portion of the capsule as a specialised band of fibres of more or less definite individuality. Such specialised bands of capsule form one of the many classes of structures known under the name of ligaments. A ligament may therefore be nothing more than a specially strengthened portion of the primitive capsule of the joint. But it frequently happens that the capsule is strengthened, not by any develop-

ment of its own fibres, but by the addition of bands derived from other structures which primitively form no part of the capsule. Tendons of muscles may become incorporated with capsules of joints. This happens particularly in those cases in which a muscle has undergone some phylogenetic shifting, where in the course of postural changes its origin or its insertion has migrated. Such tendons also are known as ligaments. Other structures may degenerate in the neighbourhood of joints, and their remains become added to the capsule, and are then known in descriptive anatomy as ligaments of the joint. Few of these disturbing factors occur in any of the joints which directly concern us, but the student should bear in mind that when he reads of capsular ligaments they may be nothing more than simple thickening of the capsule, as the gleno-humeral ligaments of the shoulder; they may be derived from the tendons of muscles, as the posterior ligament of Winslow in the knee ; or they may be degenerated remains of other structures, as the so-called long internal lateral ligament of the hinge of the jaw.

Within the joint cavity complications may arise from foldings of the synovial membrane and the development of fat in synovial recesses. Intra-capsular fat is always present where a non-articular portion of bone is included within the limits of the capsule. As an example of this we might instance the fat pad on the intra-capsular but non-articular portions of the olecranon process in the elbow joint. It is an old observation that fat pads are present in joints which bear pressure, but are absent in those which do not. The shoulder joint is notorious for the simplicity of its synovial membrane and the absence of any intra-articular fat. No fat is present in any of the joints of the wrist or hand.

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Another factor that may complicate joint cavities is the sinking into the cavity of tendons (such as the biceps in the shoulder and the popliteus in the knee) or of specialised portions of the capsule (such as the ligamentum teres of the hip). No intra-capsular ligaments are present in any of the joints of the hand.

A much more complex modification of the joint cavity is the development of so-called interarticular fibro-cartilages. There

is but little doubt that structures of many types and functions are grouped together under this name, and that a common morphology does not apply to them all. In general, they are said to be present in joints to make a more perfect adaptation of bony surfaces which otherwise do not fit each other with great nicety. It is difficult to believe that Nature could not fashion the articulating bones to make an accurately fitting joint, and so adopted a plan of inserting washers to complete the adjustment. " Cette explication de l'existence des fibro-cartilages interarticulaires est loin de me satisfaire " was the summing up of Poirier after much research upon the matter, and it is a conclusion which probably most will come to. Nor does the explanation that an interarticular fibro-cartilage permits of more than one type of movement being carried out in one joint prove satisfactory in all cases. It is easy to point to the interarticular fibro-cartilage in the joint of the jaw and to say that the gliding movement typical of the herbivore's chewing takes place above it, and the hinge movement typical of the carnivore's biting takes place below it, and so in mixed feeding Man these two movements can be combined in one joint. Other considerations come into this question. In the first place, all mammals (except monotremes) possess this interarticular fibro-cartilage, no matter if they be chewing herbivores or biting carnivores or mixed feeders; and, in the second, an almost exactly similar disc is present in the sterno-clavicular joint, where no one but an enthusiast could claim this functional *rôle* as an explanation of its presence. It is not at all impossible that the interarticular fibro-cartilage is present in these two joints because the moving bones are membrane bones which have no cartilage in their composition, and that therefore the bearing surfaces have to be a product of the mesoblast which primitively fills the joint cavity. All interarticular fibro-cartilages are, however, not of this type, and each one must be considered on its own merits. In the hand one such cartilage is present as the triangular fibro-cartilage of the wrist joint, to which some attention has been already directed in studying the carpal bones.

By far the most interesting departure from the very primitive condition we have pictured is displayed in the ends of the

articulating bones. In the very simple joint we have pictured, such as the joint between a rib and the sternum, the unossified extremity of the bone forms the articular cartilage covering the moving surface of the bone. A considerable portion of the sternal end of a rib remains unossified as the costal cartilage, but in the limb bones so large a proportion of cartilage is not compatible with stability, and the whole shaft must be consolidated into firm bone. A further specialisation is therefore seen in a limb joint such as the carpo-metacarpal joints. Here the articulating bones ossify completely, but the end of each bone remains covered with a film of hyaline cartilage which is capable of renewing itself, and so repairing the ordinary results of wear on the bearing surface. This specialised cartilage of the articulating end of the bone is developed necessarily at that portion of the bone where the periosteum becomes continuous with the capsule of the joint. But in most of the limb joints this cartilaginous end of the bone becomes highly developed, and projects into the cavity of the joint as a cushion that varies in its shape in accordance with the movements which are carried out in the adult joint. In such a case the developing bone ossifies up to the line where the periosteum becomes continuous with the capsule, just as it does in the less specialised joint, but the specialised cartilaginous cushion upon its end projects freely into the joint cavity. This cartilaginous cushion is known as an *epiphysis*. As growth proceeds ossification commences in the epiphysis itself, but this ossification is separate from that o the shaft of the bone. As ossification continues the epiphysis becomes converted into bone, but this bone continues to be surrounded by cartilage ; it is covered over the whole of its free articulating area with articular cartilage, and between it and the bone in connection with which it was developed there remains a cartilaginous area known as the *epiphysial line*. From this epiphysial line the periosteum leaves the bone to form the capsule, just as it does in the more simple type of joint. Epiphyses are therefore separate ossifications developed in joint cavities as specialisations of articular cartilages. They may be regarded as distinct bones or *ossa intra-articulare*, which are united to the limb bones by that type of junction known as a

synchondrosis. The purpose of epiphyses has been very variously estimated by anatomists. That they are concerned in the problem of the growth of bone is undoubted, but rather different views are held as to the part they play in the business. When growth of the limb bones is completed the epiphyses become fused to the bones with which they are connected—the synchondrosis of union becomes a synostosis—and shaft and epiphyses become an entity by the disappearance of the cartilaginous epiphysial line. The presence of a cartilaginous epiphysial line is therefore a sign that growth of the bone is continuing, and its absence is evidence that growth has ceased. For this reason it has been thought that the growth of bone takes place from the epiphysial line, and that the epiphysis is the agent of growth rather than a mere expression of growth. But bones, both the bone of the epiphyses and the bone of the shaft, grow by interstitial calcification of their cell elements, the calcification being produced by a series of changes in the tissues brought about by the deposition of calcium salts carried to the growing bone by the blood-vessels. The arteries reach the bone *viâ* the specialised fascial investment, or periosteum, either as minute twigs from neighbouring arteries, or as larger and more definite channels which penetrate into the bone substance and are known as *nutrient arteries*. In this way bones grow in bulk. They grow in length in exactly the same manner, one end being generally selected as the site of maximum growth. More blood is needed at the most rapidly growing extremity of the bone, and so larger nutrient arteries are present here, the nutrient artery running into the substance of the developing bone and breaking up into small vessels in the calcifying cells of its interior. As calcification proceeds solid bone becomes formed around the

FIG. 66.—Diagram to show the relation of periosteum, capsule and epiphysial line in a joint in which the articulating bones bear epiphyses.

entering arteries, and permanent nutrient foramina are developed for the admission of vessels. Through these nutrient foramina the vessels run towards the growing ends of the bones. Now, suppose we imagine the adjacent ends of two bones articulating at a joint. Each bone is growing by additions to its substance between the joint line and the entrance of its nutrient artery.

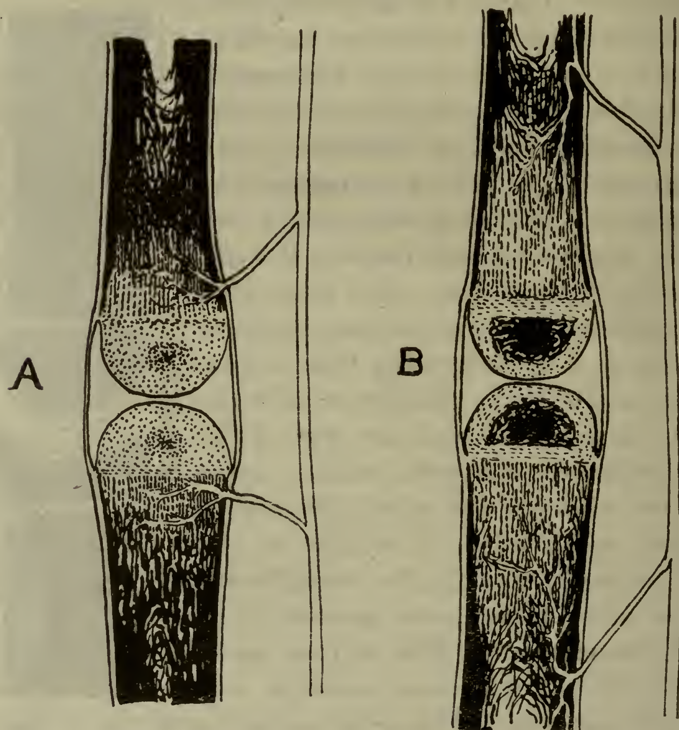

Fig. 67.—Diagram to show the reversal of the nutrient arteries. In A the arteries run into the growing bone towards the joint. In B the growth of a new bone between the entrance of the artery and the epiphysial line has led to the reversal of direction of the nutrient arteries.

There is therefore an ever elongating interval between the point of entry of the artery and the end of the bone, and so there is an ever elongating interval between the nutrient artery supplying one bone and the nutrient artery supplying the next. But these vessels arise from a main artery which is running down the axis of the limb, and the result of these changes will depend upon the relative growth of this vessel compared with the

rapidity of the bone growth. If the bones are growing rapidly, then they will outstrip the artery, and the nutrient vessels will change their direction, for they will cease to run from the main vessel towards the joint line, and be turned so that they run away from the joint line and towards the centres of the shafts of the bones. As they change their direction their openings into the ossified bones alter, for their foramina of admission will be adapted to their new course. In this way we may say that nutrient arteries will run away from the joint line at the ends of articulating bones in which rapid growth is taking place, or towards the joint line when that is the less rapidly growing end. All this change at the growing end of bones takes place without disturbing the relations we noticed previously. Cartilage is changed into bone; the bone grows longer and more massive; it alters in size and form, but always the periosteum clothes it to the cartilaginous end, and always the periosteum leaves it at this point to become the capsule of the joint. Within the capsule is the epiphysis in which ossification is also taking place, but always existing as a neutral zone between the growing shaft and the growing epiphysis there remains the cartilaginous epiphysial line. From this line the periosteum departs to form the capsule. The epiphysial line is not a line of growth, but rather a line which separates two areas of growth, and perhaps the best picture of its function is gained by regarding it as an *adjustment line.* It is all-important that in the growing animal the joint line should remain constant, in order to permit the proper functioning of the limb. For instance, the line of the knee joint must be maintained by the accurate adaptation of the femoral and the tibial articulating surfaces in a constant plane. But, as the bones of the pelvis and of the thigh and leg are constantly changing in the process of growth, the joint lines would be liable to alteration were it not possible to produce readjustment and restore harmony at the neutral epiphysial lines. We may therefore regard epiphyses and epiphysial lines as elaborations of articular cartilage developed for the preservation of joint adaptations in growing parts. The epiphysis is the adjustable pad at the end of a bone which maintains its capacity for readjustment so long as the bones retain their capacity for

growth. When bones have ceased to grow, the line of readjustment becomes unnecessary, and epiphysis and shaft are welded into one. We should therefore look to see the epiphyses persist longest as independent structures at the ends of bones in which growth is dominant, and we are prepared to find that those epiphyses towards which the nutrient arteries are directed become consolidated to the shaft before those from which the nutrient arteries run. But it may be urged that there are some joints upon which the growth of bones must produce constant change which will show no epiphyses at the extremity of the mobile bone. Two such joints may be instanced: the joint of the jaw and the sterno-clavicular joint. Here no true epiphysis is developed, since the moving bones are not pre-formed in cartilage, and, as we have already seen, the need is met by the development of an adjustable interarticular fibro-cartilage within the joint cavity.

We have seen that the epiphysis is developed and remains within the joint cavity. It is therefore not covered by periosteum, or by that derivative of it termed perichondrium, as other cartilages are. Its surface is not even clothed by the synovial membrane which lines the capsule of the joint. Articular cartilage therefore presents the remarkable condition of being a tissue which is absolutely naked, bare cartilage of one bone playing directly upon bare cartilage of its neighbour. It is for this reason that erosions of cartilage are so common a feature of joint disease.

In what we may term the undisturbed condition of the joint the periosteum becomes continuous with the capsule of the joint at the epiphysial line, but this condition does not persist in all joints, for varying disturbing factors may produce changes. To permit of freer movements, the capsule may be distended, and then it becomes folded back over the end of the shaft of one or both of the articulated bones; in this way the capsule appears to be attached, not at the epiphysial line, but at a line some distance along the shaft of the bone. It is in this manner that the "reflected" fibres of the neck of the femur in the hip joint are produced. Again, serous spaces, as bursæ developed beneath muscles, may make secondary connection with a joint

capsule, and so produce an enlarged and compound cavity which in descriptive anatomy is simply designated as capsule. It is thus that the knee joint is enlarged by the post-natal fusion with the sub-quadriceps bursa, and the capsule in the adult joint appears to arise some distance up the front of the shaft of the femur. Or, on the other hand, the whole of the epiphysis may not be articular, and then the capsule will become adherent to the bone, as periosteum, for some distance between the epiphysial line and the articular margin. This change may be brought about by a phylogenetic reduction of articular surface or by the invasion of the epiphysis by muscles or tendons.

In dealing with the individual joints of the hand, we have to note those at which the separate joints of the digits are moved, those which exist among the individual bones of the carpus, those by which the carpus is moved upon the metacarpals and the radius, and, finally, that by which the radius and ulnar articulate at their lower ends. The inferior radio-ulnar joint exists between the fixed ulnar and the rotating radius, and at it the hand is turned palm up (supinated) or palm down (pronated). The power of pronation and supination is an ancient mammalian possession, but it is one which is lost in all mammals which are typical quadrupeds, and one which is retained in few animals in such a perfect condition as that seen in Man. The capsule of the joint needs but very brief note. Behind and in front it passes from radius to ulna as a continuation of the periosteum of the lower ends of these bones. Above, in the interval between the two bones, it is attached to the epiphysial lines of the two bones upon either side, but it commonly is inflated upwards into a definite pouch in the middle. This pouch is known as the *membrana sacciformis*, and its upmost recess passes upwards on the ulnar side between the interosseous membrane and the lower fibres of the pronator quadratus. The upper limit of the membrana sacciformis therefore extends above the epiphysial line of the two bones.

The so-called triangular fibro-cartilage contains, as a rule, the merest trace of cartilage at the site of its broad attachment to the articular cartilage of the radius, its narrow attachment to the styloid process of the ulna being composed of fibrous

tissue similar to that typical of other joint capsules. The normal ligament shows no opacity to the passage of X-rays. Very occasionally a small nodule of cartilage is apparent upon X-ray plates of this joint, but this little nodule is not situated in the thickness of the ligament, nor is it at its radial extremity (see Fig. 68). It exists below and lateral to the styloid process of the ulna, and represents the adult persistence of a cartilaginous mass which is commonly present in the fœtus at the second month, and has been said by Milenius (*Morph. Arbeit.*, Vol. V., 1895) to represent the os intermedium. The normal structure to which the name triangular fibro-cartilage applies, is merely the inferior portion of the capsule of the inferior radio-ulnar joint, brought into its present position by the changes that have taken place in the styloid process of the human ulnar.

At the radio-carpal joint the hand is moved towards the ulnar side and towards the radial side, and is bent toward the palmar and dorsal surface upon the forearm. At the intercarpal joints this mobility is increased by movements between the individual bones of the carpus.

The separate carpal bones are held together by a common capsule which makes a complete cuff, enveloping the carpus and passing to the radius and ulna above, and to the metacarpal bones below. This capsule presents a great number of more or less definite strands running between neighbouring bones, and each of these strands has been described and named as a separate ligament. Here we will content ourselves with the somewhat more crude, but none the less practical, method of treating the whole as the capsule of the carpus. The capsule of the carpus becomes continuous with the periosteum which clothes all the carpal bones upon the dorsal and palmar surfaces, and along the radial and ulnar margins of the carpus. It is also continuous with the periosteum of the radius and ulnar above and with that of the metacarpal bones below. Within this fibrous capsule the carpal bones are strung together by ligaments which pass between adjacent surfaces of the bones, and so subdivide the synovial space contained within the carpal capsule. These ligaments are known as the interosseous ligaments. It is interesting that the interosseous carpal ligaments are arranged

very much in the same way as the wires used by the articulators, for the carpal bones are strung together in two rows by ligaments which pass in a transverse direction between the bones. An interosseous ligament passes between the semilunar and the scaphoid, and between the semilunar and the cuneiform, and thus the first row of the carpal bones is strung together, and the synovial cavity of the radio-carpal joint is cut off from the

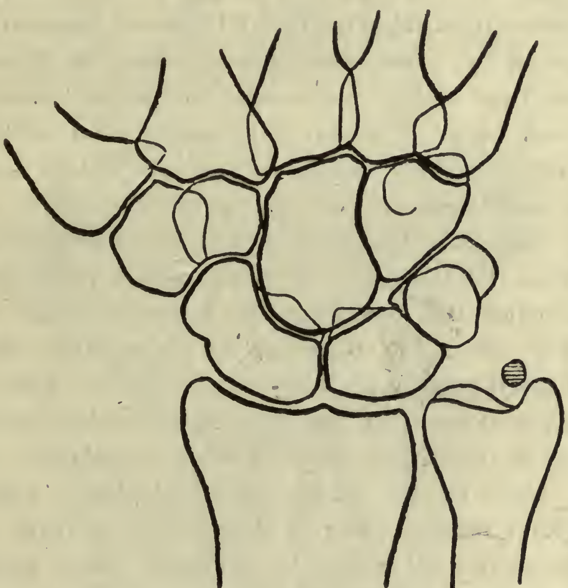

FIG. 68.—Tracing of an X-ray of the wrist joint in which a small nodule is present in the fibrous tissue attached to the styloid process of the ulna. This X-ray also shows the separation of the unciform from the semilunar.

synovial cavity of the midcarpal joint. In the same way interosseous ligaments unite the trapezium to the trapezoid, the trapezoid to the os magnum, and the os magnum to the unciform, thus stringing the second row of the carpal bones, but not completely shutting off the midcarpal joint from the carpo-metacarpal joints, as the ligaments passing between the trapezoid and the trapezium and os magnum are usually represented by fine cords which do not reach to the dorsal and palmar surfaces of the carpal capsule. There is only one interosseous ligament, and that is an inconstant and incomplete one,

which unites the two rows of carpal bones. This is the occasional band of tissue which joins the distal end of the scaphoid to the radial margin of the os magnum. It is this ligament which has been selected by some authorities as the adult representative of the embryonic nodule of cartilage which is developed as the independent os centrale. Its sole practical interest consists in the fact that when it is well developed it may form a barrier in the synovial cavity of the midcarpal joint, and that the site of its attachment to the os magnum is sometimes marked by a deep notch conspicuous in X-ray plates. The articulations of the two rows of the carpal bones need not be described, but it is worth while noting that, although the tradition of our text-books demands an articulation between the semilunar and the unciform, this articulation is by no means constant. Were the description of the carpal articulations to be written from the thousands of X-ray plates taken during the war, this articulation could only be described as an occasional one. Very often the unciform and semilunar are widely separated in all positions which the carpus can assume; this is particularly well shown in Professor Bryce's illustrations of the movements of the carpal bones (Quain's "Anatomy," 11th ed., Vol. IV., Part I., Figs. 235—237, and *Jour. Anat. Phys.*, Vol. XXXI., 1896–7), and is shown here in Fig. 68. The pisiform does not enter into the common carpal articulations within the carpal capsule, its articulation with the cuneiform having its own special capsule and its own separate synovial cavity.

Of the carpo-metacarpal articulations that between the basal element of the thumb and the trapezium is the most independent and the most remarkable. The capsule and the synovial cavity are distinct from all the rest of this series of articulations, and no interosseous ligament binds the metacarpal of the thumb to that of the index. The curious saddle-shaped articular facet on the trapezium which admits of the peculiar mobility of the joint is of great interest. In the first place, it imparts a special freedom of movement to this joint, so that any muscle which acts upon the joint may in certain circumstances avail itself of this peculiarity of joint contour

to produce movements not usually regarded as its normal action. In this way the movements of the thumb may prove a very fallacious criterion in cases of paralysis of certain muscles. In the second place, this peculiarity of the carpo-metacarpal articulation of the first digit of the hand is no human speciality, for it is known to occur in the skeletons of the earliest mammals

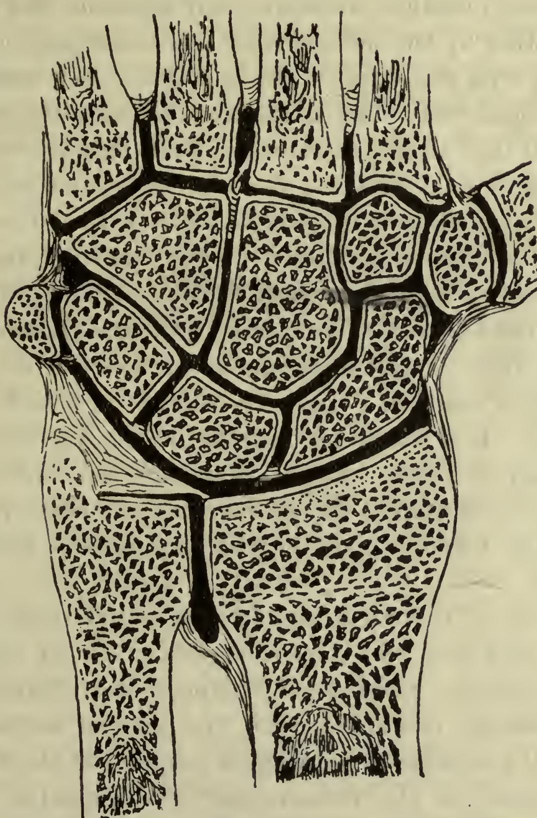

FIG. 69.—The articulations within the capsule of the carpus.

of the Eocene period. The articulation of the index metacarpal with the trapezoid is peculiar, as we have already seen, by reason of the deep notch in the base of the metacarpal into which the trapezoid is received. The metacarpal of medius is firmly implanted against the corresponding broad articular surface of the os magnum, and is further rendered stable by an interosseous ligament which unites the ulnar side of its base with the adjacent

surfaces of the os magnum and unciform, being attached to these two bones near to the point where they are bound together by their own interosseous ligaments. The metacarpals of annularis and minimus both articulate with the unciform by simple cartilage-covered surfaces, which permit of a fair degree of movement taking place at these joints. The metacarpal bones of index, medius, annularis, and minimus also articulate with each other by the sides of their bases, and just beyond this articulating area these bones are bound to each other by interosseous ligaments. The articulation between the metacarpal of index and that of medius is made by one long facet occupying the whole area of contact of the two bones, and being convex on index and concave on medius. The articulation between medius and annularis is effected by two articular surfaces, for the interosseous ligament which binds medius to the carpus subdivides the long articular surface present between the other bones. A single simple articular facet concave on annularis and convex on minimus permits the mobility between these two metacarpals. It is worthy of note that in the Anthropoids each intermetacarpal joint, except that between minimus and annularis, is subdivided by an interosseous carpo-metacarpal ligament, the intermetacarpal articular surfaces being double in each case.

The heads of the metacarpal bones of minimus, annularis, medius, and index are joined together, as we have seen, by the transverse metacarpal ligament, this band of fascia being intimately connected with the ventral surface of the capsule of the metacarpo-phalangeal joints. At these joints the rounded heads of the metacarpals—the knuckles—articulate with the concave bases of the proximal phalanges, and both articulating surfaces are carried on epiphyses. At the interphalangeal joints only one of the articulating surfaces—that of the base of the distal bone—is epiphysial. The metacarpo-phalangeal, and the interphalangeal, joints are all of one type, and no elaborate description will be attempted. Lateral movement is reduced to a minimum in the interphalangeal joints, although a certain side-to-side play exists in the metacarpo-phalangeal joints to permit of splaying the fingers apart and

drawing them together again, this difference in lateral mobility being evidenced in the different contours of the distal extremities of the metacarpals and phalanges. Flexion is permitted in all the joints to a right angle at least, and extension to the straight line. Each joint possesses a capsule of which the dorsal portion is reinforced by the dorsal expansions from the extensor tendons, the palmar portion is specially thickened behind the sheaths of the flexor tendons, and the lateral portions are specialised into definite ligamentous bands. The lateral ligaments are attached to the dorsal aspect of the side of the head behind, and to the palmar aspect of the base of the bone in front. This oblique direction of the lateral ligaments is particularly well marked in the case of the metacarpo-phalangeal joints, and it is easily seen that as the joint is flexed these ligaments become tightened. If the lateral mobility of the fingers be tested as the digits pass from full extension into full flexion, the range of movement will be found to decrease as these ligaments are tightened upon flexion. The palmar portion of the capsule is somewhat complicated, especially in the case of the metacarpo-phalangeal joints, where the interphalangeal ligaments become blended with the capsule. In addition to this, there is a special thickening of the palmar ligament which is sometimes known as the glenoid ligament. These special thickenings of the capsule are far more firmly attached to the base of the bone in front than they are to the head of the bone behind. They are of great practical importance, for if a digit be forcibly bent backwards they may be torn from the head of the bone behind as the joint becomes dislocated. When the dislocation is reduced it sometimes happens that the torn ligament is tucked into the joint between the articulating bones, and recurrent dislocation under these circumstances is by no means rare, especially in the case of the thumb. To the glenoid ligaments of certain finger joints are attached little nodules of cartilage, or little masses of bone which are named sesamoid bones, from their resemblance to grains of wheat.

CHAPTER XIV.

THE SESAMOID BONES.

"THE sesamoid bones, resembling the grains of Indian wheat, are certain very round small Bones, somewhat flat and spongy within. They adhere at the Joynts to the tendons of the muscles that move the fingers and toes, and with them in the boyling of dead Carkasses, and the purgation and denudation of the bones are utterly lost unless great care be taken to preserve them." It would be a difficult matter to find in any modern text-book of anatomy an account of these curious little bones so full and so good as that given by Diemerbroeck (1609—1674), from whose work this quotation is made. The interest which is attached to the problem of the sesamoid bones attracted many of the older anatomists, but of recent times it appears to have been mostly lost sight of. The student generally pays but scant attention to them in practical anatomy, and if they should excite his curiosity, he learns but little of them by consulting his text-books. Their exact number, their precise associations, and their functions are among the details which are commonly lacking when information is thus sought. And yet, the digital sesamoids are extremely interesting bones, and one at least—that of the great toe—is of practical surgical importance. Most of our ideas concerning sesamoids are taken from observations upon that prince among sesamoids, the patella, but in certain ways this is a very specialised bone and is not typical of its kind.

FIG. 70. — The sesamoid over the metacarpo - phalangeal joint of the fifth digit of a rabbit.

In what may be regarded as their full development, the

digital sesamoids are little bones, shaped like dumb-bells, which are adherent to the palmar part of the capsule of the metacarpo-phalangeal and interphalangeal joints, and lie transversely to the axis of the digits. Across the grip of the dumb-bell runs a groove which acts as a pulley surface for the flexor tendons. Such digital sesamoids may be seen in the feet of the rabbit (see Fig. 70). In Man this degree of perfection is not attained to, the grip of the dumb-bell is absent, and two separate little bones, representing the ends of the dumb-bell, exist in the most complete form, or only one little bone, representing one end of the dumb-bell, in cases where the condition is less perfect. They are developed as cartilaginous nodules soon before the third month of fœtal life, and remain as cartilage during childhood, ossification commencing at about the fifth year from a single centre. Their number is inconstant. According to Vesalius, " sesaminia ossicula in singulis manibus ut minimum occurrunt duodecim, ac proinde jam vigintiquatuor illa in manibus statuamus " (" Fabrica," Liber I., cap. 39, p. 113). Diemerbroeck makes a very similar statement, for he says: " The number of these bones is not always the same, for sometimes twelve are found in each hand and foot, sometimes fewer, sometimes more." It is a very interesting thing that Vesalius should here follow the teaching of Galen in allowing that the sesamoids of the human hand were so numerous, for the conjecture of Eustachius (1513—1574) that the Galenical teaching was derived solely from the study of lower animals is almost certainly correct. (See " Opuscula Anatomica," " Ossium Examen," p. 186, 1707.) Of recent years Pfitzner has paid great attention to the relative frequency with which these bones are met; and an examination of numerous X-rays taken during the war has confirmed his main conclusions. In practically every case the bones exist at the flexor surface of the metacarpo-phalangeal joint of the thumb. These ossicles are adherent to the volar ligaments, and represent the two extremities of the dumb-bell-shaped bone. It is rare to find these bones absent in the adult. As a rule, the radial-sided bone is larger than its fellow, and almost always it is of a more elongated form. Two similar bones, or only the radial member of the pair, are by no

means infrequently present on the flexor surface of the proximal interphalangeal joint of the thumb. One bone upon the ulnar side of the metacarpo-phalangeal joint of the minimus is present in 76·5 per cent. of all cases according to Pfitzner, or 70 per cent. according to Alby, and from the examination of X-rays of soldiers' hands one would be inclined to regard its absence as quite an unusual event. The same finding applies to the radial-sided sesamoid of the metacarpo-phalangeal joint of index. It is certainly very much more frequent in the average British soldier than the 42 per cent. determined by Alby, or the 45·9 per cent. by Pfitzner (see Plate II.). Sesamoids in relation to other metacarpo-phalangeal joints, or to the interphalangeal joints, are distinct rarities. In the foot, the pair of bones at the metatarso-phalangeal joint of the big toe is constant, and the bones are larger than any in the hand, but sesamoids in relation to other joints are far more rare than in the case of the hand, and these occasional bones are, as a rule, small. We may agree with Diemerbroeck that " in the hands they are bigger than in the feet, except in the great toe, to which the biggest is fastened at the head of the Metapedion bone." Concerning this sesamoid a rather curious piece of information is added, for the author continues : " But this biggest of all, which resembles the half of a Pea, both for shape and bigness, is by the Arabians called *Albadaran*, of which the Jews fain many fables, as they do of the bone Lus." Apart from its fables, this bone is of interest, since it is of sufficient size to be fractured and to present a very definite surgical problem.

Fig. 71. — The sesamoid bones over the metacarpo - phalangeal joint of the human thumb.

Many have speculated as to why, in general, digital sesamoid bones are so variable in their presence, and several suggestions have been put forward to account for their development. Monro Primus laid down three conditions which determine their presence (" The Anatomy of the Human Bones," etc., p. 305) :

"(1) That wherever the tendons and ligaments are firmest, the action of the muscles strongest, and the compression greatest, there such bones are most commonly found. (2) That, *cæteris paribus*, the older the subject is in which they are sought, their number is greater, and their size is larger. (3) The more labour any person is inured to, he has, *cæteris paribus*, the most numerous and largest ossa sesamoidea." With regard to (1), pressure has often been appealed to as the causative agent, and the sesamoids of the hand might for some prove that at one time the human hand was used for quadrupedal progression, but in other parts of the body (such as the back of the knee) sesamoids do not develop in sites subjected to pressure, and the fact that the sesamoids of the hand are more numerous, more frequent, and better developed than those of the foot appears to negative this assertion in a very decided way. Age and work have both been asserted by Gillette and many others to be factors in producing the development of sesamoids, but the work of Pfitzner has not confirmed this, and X-ray examinations appear to disprove it altogether. Probably no theory which regards these bones as merely sporadic ossifications developed by pressure, like bursæ, or produced as a part of that process of calcium deposition in tissues which typifies senility, will ever prove helpful in interpreting the story of the sesamoids. It is more to our purpose to inquire what are their anatomical associations in those animals in which their development is carried to a further state of perfection than that seen in Man. When the bones are developed in their dumb-bell form, the grip of the dumb-bell forms a pulley groove over which the long flexor tendons run, and at the two knobs of bone at either end are the flexor insertions of the short intrinsic muscles. When the little bones are unconnected by an intervening bar, a fibrous groove between them lodges the long flexor tendons, and each bone furnishes a flexor insertion for the short muscle. In whatever animal metacarpo-phalangeal sesamoids are found, they are always present in association with the short intrinsic digital flexors.

Even when the conditions of the hands have become so profoundly modified as they have in the horse, the remaining sesamoids are present in that altered form of the short flexor which

is known in veterinary anatomy as the "Suspensory Ligament." It is from this point of view that the sesamoids have their chief interest: they are the tell-tales of the presence of short digital flexors. They are not produced by pressure or hard work, they are not caused by old age, but they are ossicles in the tendons of insertion of a fluctuating group of intrinsic muscles which produce flexion of the metacarpo-phalangeal joints. To these little bones we shall return in dealing with the short muscles of the hand.

CHAPTER XV.

The Action of Muscles.

Before we attempt to describe the muscles of the hand and define the several actions which the contractions of their fibres are capable of producing it is necessary to examine very briefly the general principles of muscular action, and to define the terms used to denote the actions in which muscles play a part. In confining our attention solely to the muscles of the hand we limit ourselves to the study of skeletal, striated, or voluntary muscle. The skeletal muscles have always been known as voluntary muscles, since they are said to be under the control of the will; but from the point of view of any individual skeletal muscles this definition needs examination. For instance, the muscle known as the supinator brevis is a typical voluntary muscle; it is familiar to every one who has made any study of anatomy. We may know exactly where the muscle is, what it looks like, and what nerve supplies it, but it is beyond the power of our wills to send an impulse along that nerve and make the muscle contract. It is not under the control of the will as an entity, for the will is powerless to cause it to move. Before we can produce a voluntary contraction of the supinator brevis we must know what action it produces in the body. From a study of its disposition, and a knowledge of the limitations produced by its paralysis, we conclude that it acts in supinating the forearm. The act of supination of the forearm is one that is under the control of our will. We may send a command from the brain, and produce a desired supination of the forearm; in this action the supinator brevis takes part. The supinator brevis acts in a voluntary movement. It acts in a movement that is under the control of the will, but only to that extent is it a voluntary muscle. It is the movements of joints and parts, and not the actions of muscles, which are voluntary and under the control of the will. The reason for this is to be sought in a

study of cerebral functions, and we may fall back upon the old dictum that " movements, ~~not muscles~~, are represented in the cortex." In the grey matter of the motor areas of the brain are represented those movements of the body of which the animal has a definite pictured cognisance, and it is from these cortical motor areas that these conscious pictured movements are initiated. We can therefore only will—by an effort of the cortex—those movements of which we have a concrete and conscious conception. But there are other movements of which we have no concrete mental picture, and these are initiated not from the cortex, but from the basal ganglia of the brain. In the carrying out of these movements the non-striated or involuntary muscles are largely employed ; and these muscles are involuntary, not because they are in themselves less under the control of the will than are the voluntary muscles, but because the movements which they perform are not movements of which we have full pictured cognisance, which are not represented in the cortex, and so are not under the control of the will.

We have a definite concrete picture of the action of bending a finger. This action is initiated from the cortex, and is therefore under the control of the will. The muscles which produce this bending are said to be voluntary muscles. But we have no definite concrete picture of closing the pyloric orifice of the stomach. This action is initiated from a lower centre, and is therefore not under the control of the will. The muscles which produce this closure are said to be involuntary muscles.

But in several involuntary acts of which we have no cortical picture—such as the complex act of sneezing—many of the so-called voluntary muscles are employed. Sneezing is not initiated from the cortex, and the action of the voluntary muscles taking part in it is determined by the lower centres. Now suppose a damage to the motor cortex destroys an area which contains the " action pattern " of a voluntary movement in which a certain voluntary muscle acts ; then this particular action cannot be performed, and the muscles which should produce it are " paralysed." But some of these muscles may also take part in an involuntary action, as some of the muscles

attached to the arms do in sneezing; then, when the involuntary act is performed, these muscles, which are completely paralysed for the voluntary act, will contract in a perfectly normal way. A voluntary muscle may therefore be paralysed for a voluntary or pictured action, and yet be perfectly free to act in an involuntary or unpictured action. The distinction between involuntary and voluntary muscles is therefore rather one of the actions in which they are employed than of any actual characteristic of the muscle itself.

No part of the body displays the functions of voluntary muscles so well as does the hand, for no part of the body possesses a greater range of purposive voluntary movements. The hand has allotted to it a most thorough cortical representation, and the actions of all its parts are therefore capable of education to a very high degree.

A muscle is a contractile mass of tissue which is fixed at its two extremities to some firm structures, generally bones, and which acts by contracting and approximating its two extremities. When a muscle contracts it is usually so placed anatomically that one end is relatively fixed whilst the other is free to move. The end which is relatively fixed during action is termed the origin, and the end which is free to move is termed the insertion. Thus the flexors of the fingers have their origin in the relatively fixed arm or forearm, and their insertion into the movable bones of fingers. But the terms "origin" and "insertion" cannot be used in any very hard and fast manner, for the extremity which is the fixed origin of a muscle during one action may be the movable insertion during another: the rectus muscles of the abdomen may pull the pelvis up towards the ribs, or pull the ribs down towards the pelvis. More than that, in the ordinary physiological use of parts the moving point of a muscle in the upper extremity may be the fixed point of the corresponding muscle in the lower extremity. In contrasting the action of the muscles of the hand and foot the use of the terms "origin" and "insertion" may lead to great confusion.

When a cortical area sends forth a volition for the performance of a definite movement, the muscles which produce this movement are termed the *Prime Movers*. Thus when we wish to

bend the wrist the flexors of the wrist joint are said to act as prime movers. The origin of these prime movers for this action is in the arm; their insertion is into the hand. Certain definite laws govern the action of all prime movers.

(*a*) Save in certain exceptional cases, and when only very slight movement is produced, an individual muscle does not act alone as a response to a volition. Movement is effected by the action of muscles working in groups. This circumstance is merely an extension of the fact that muscles are not represented cortically, and that movements involve, as a rule, more than one muscle for their proper performance. (*b*) A muscle does not

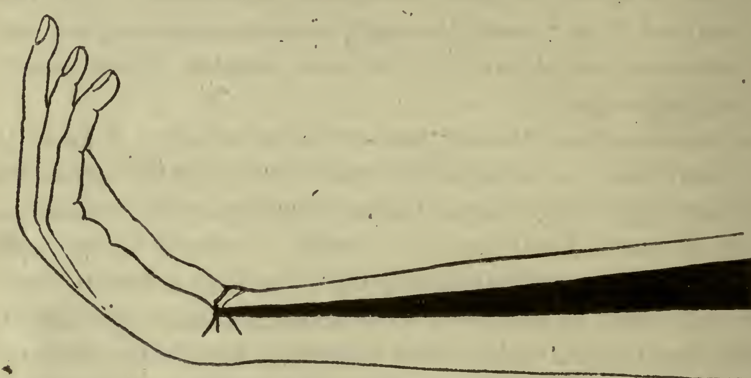

FIG. 72.—*Volition*—flexion of the wrist. The flexor carpi ulnaris acts with the flexor carpi radialis as a *Prime Mover*.

necessarily do in life what the dissected muscle, or a mechanical contrivance, will do in the cadaver. Neglect of this fact has led to many errors in teaching. (*c*) A muscle acting as a prime mover in life does not necessarily do all the actions that a complex anatomical arrangement of its fibres permits it to do when passively stretched in the cadaver. When a muscle can perform many actions it, as a rule, produces but one of these actions in the living subject when acting as a prime mover, and the rest of the actions of which it is anatomically capable are evoked only when it acts in a capacity other than that of a prime mover. (*d*) A muscle which is anatomically capable of producing opposed movements does not, as a rule, perform these two movements when acting as a prime mover during life. It

will produce one movement as a prime mover, and act in the other only in some other capacity. (*e*) A muscle acting as a prime mover will not do its work if gravity will do it instead. This is an important law of muscular action which is often disregarded in examining the movement of living subjects. (*f*) A muscle need not act as a whole to perform a minimal effort. As more effort is demanded more fibres are brought into play, and muscle after muscle is called upon for assistance in regular order as the need for muscular effort becomes greater. This physiological law is merely a consequence of the fact that—(*g*) Every muscle fibre acts to its utmost, and only

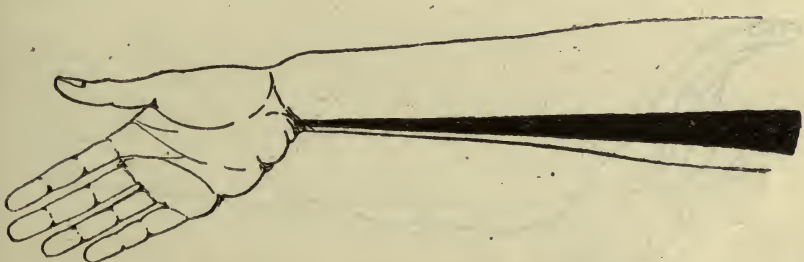

Fig. 73.—*Volition*—ulnar deviation of the hand. The flexor carpi ulnaris acts with the extensor carpi ulnaris as a *Prime Mover*.

sufficient fibres are called into action to perform the demanded task. As the task becomes more difficult more fibres are brought into play, and every fibre which acts does so to its full capacity. In other words, muscles go full steam on half-boilers, and not half-steam on all boilers.

Prime movers do not act alone, for their stimulation by a volition brings about some change in the muscles which produce the opposite movement. These opposed muscles are then said to act as *Antagonists*. Thus the flexors of the wrist are the prime movers in the performance of a volition to bend the hand towards its palmar surface, and the extensors of the wrist are the antagonists in this action.

Practically every muscle has its antagonist, and it is evident that during the action of every prime mover the antagonist must be undergoing change of some kind. Naturally when the

prime mover contracts and moves the part the antagonist must relax and be moved ; but to dismiss the action of antagonists by saying that they are inhibited, and undergo a relaxation, is to overlook some important facts concerning their action. (*a*) In most ordinary muscular acts the relaxation of the antagonists is by no means a simple passive inhibition of action, for the antagonists function as controllers and regulators of the action of the prime movers. As the prime mover contracts the antagonist pays out the slack, as a man pays out a rope in which a turn is made round a windlass, and only sufficient slack is paid out, in the most carefully graduated fashion, to permit the prime mover to move the part with steadiness and precision. The

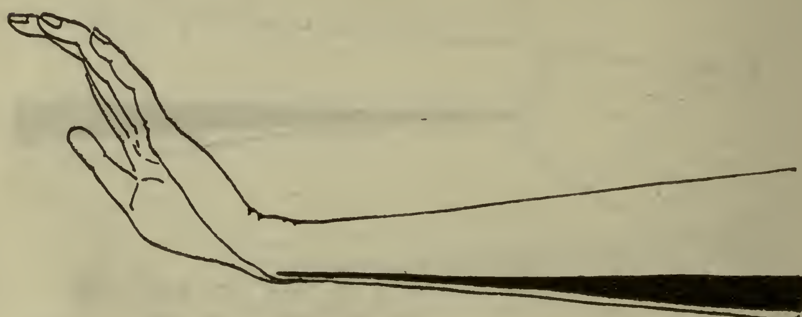

Fig. 74.—*Volition*—extension of the wrist. The flexor carpi ulnaris acts with the flexor carpi radialis as an *Antagonist* of the extensors of the wrist.

greater the nicety required in the action of a prime mover the more active a thing does this antagonistic action become. In this way the muscular work done in performing very slight, but precise, muscular movements is out of all proportion to the purely mechanical requirements of the act ; a great deal more energy is expended in the act of lifting a cup of tea from its saucer than the mere weight of the object lifted warrants. (*b*) This action of the antagonists becomes unnecessary and disappears when some outside resistance opposes the action of the prime movers. In these circumstances the antagonists merely undergo a purely passive lengthening. (*c*) In unresisted actions in which gravity performs the movement of volition, the prime movers cease to act, and the antagonists then take part in what is termed the *Action of Paradox*. An example

will make this action more clear than a description. When we wish to bend the trunk backwards we pull upon the spine with the erector spinæ muscles ; they are the prime movers. But the erector spinæ muscles only act up to the point at which the trunk is tilted definitely backwards, and gravity would complete the act. The recti muscles of the abdomen are the opponents of the erectores spinæ, and these muscles relax as the erectores spinæ begin to contract ; but the moment gravity takes charge, and the erectores spinæ cease to act, the recti begin to contract. They are the only muscles acting, but they are acting simply to prevent the trunk from toppling backwards, and the moment the backward bending of the trunk is opposed by an outside

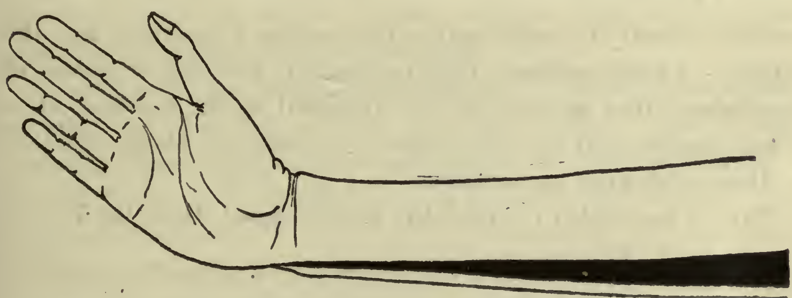

Fig. 75.—*Volition*—radial deviation of the hand. The flexor carpi ulnaris acts with the extensor carpi ulnaris as an *Antagonist* to the extensor ossis metacarpi pollicis.

force they cease to act, and the erectores spinæ commence active contraction again. This is a very simple instance. But in some other cases the action of paradox has caused confusion. The sterno-mastoid muscles, for instance, are often described as muscles which tilt the head backwards, whereas their action as prime movers is to tilt it forwards, and their contraction in the backward movement is merely an example of this action of paradox. In the movement of the limbs in which gravity is in any way involved, this action must ever be held in mind. It is easy to so arrange the part that the only muscle which contracts during extension of the elbow is the biceps, and this at times may lead to wrong deductions as to the action of muscles. (*d*) Antagonists are, like prime movers, called into play in a regular order as the need for action increases.

Another interesting and important function of acting muscles is displayed in their employment as *Synergics*. It is no easy matter to define synergic action in any very concise form; but the *rôle* that synergic muscles play is very easily appreciated by examination of the living subject. We may say that when

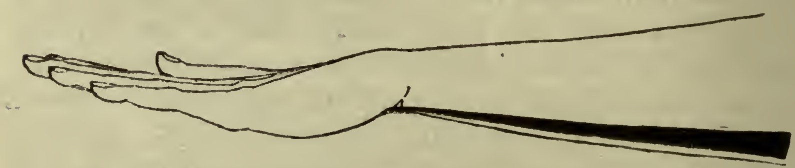

Fig. 76.—*Volition*—extension of the fingers. The flexor carpi ulnaris acts with the flexor carpi radialis as a *Synergic* to the extensor communis digitorum and extensor longus pollicis.

volition directs the performance of a certain movement, and the muscles which perform this movement are also capable of producing other movements not included in the volition, then other muscles will be called upon to counteract the production of these undesired movements.

Thus if we wish to spread the thumb apart from the rest of

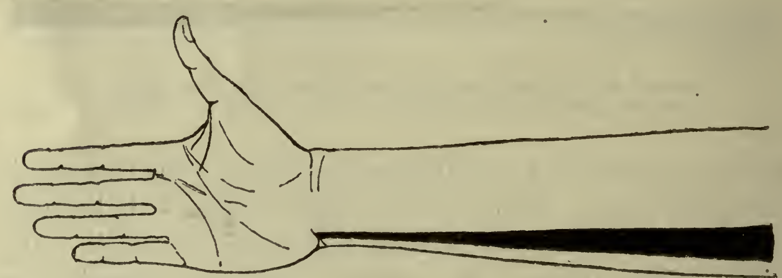

Fig. 77.—*Volition*—movement of thumb towards the radial side. The flexor carpi ulnaris acts with the extensor carpi ulnaris as a *Synergic* to the extensor ossis metacarpi pollicis.

the digits, and pull it as far towards the radial side as is possible, we employ the long abducting and extending muscles of the thumb; but since these muscles pass over the radial side of the wrist joint to reach the thumb, their contraction can also pull the whole hand to the radial side. This last action is not a part of the volition, and if it were permitted it would render the desired action less effective. It is therefore necessary to coun-

teract the action of the prime movers on radial deviation of the hand, and for this purpose the muscles which pull the hand to the ulnar side are contracted in order to keep it steady. The unconscious contraction of these synergic muscles constitutes a part of the neuro-muscular activity necessary for the proper performance of the act of volition. The example selected is one which is extremely easy to examine in its workings, for if the flexor and extensor carpi ulnaris be palpated, it will be found that they contract every time we abduct the thumb as an active voluntary movement. The laws which govern the action of synergic muscles are practically the same as those which govern antagonists, for (*a*) they are not called upon to act when the action of the prime movers is minimal, and (*b*) they are called upon to act in a definite order as the action of the prime movers becomes more powerful.

Muscles may also act as *Fixation muscles*, and fixation muscles perform their function in some cases in a manner which is very similar to that which we have examined in studying synergics, but they evince nevertheless a well-marked and distinct type of muscular activity. If we wish to do an act of precision with the fingers, we call into play the prime movers of the action ; the antagonists exert their regulating control to the utmost ; the syngergics prevent undesired actions of the prime movers. But as the business becomes more exacting fixation of the hand becomes necessary, fixation of the elbow may also be demanded, and when all our attention is concentrated upon the performance of some very delicate act, which may require only one tiny muscle for its active performance, we may in fact have to employ a host of muscles for the immobilisation of parts the movement of which would hinder the desired act.

One group of fixation muscles is of some interest from the point of view of the student of Man as a zoological type. If one is sitting comfortably in a chair with the elbows resting upon the arms of the chair, it will be noticed that if the elbow be pressed downwards towards the side, the rectus muscle of the same side of the abdomen at once goes into contraction, and that the abdominal muscles and the muscles of the loin harden. It is very surprising how slight a movement of the arm will

evoke a response in the muscles which pass from the pelvis to the ribs. The fixation of the ribs by these muscles is evidently to allow the muscles passing from the ribs to the arms to act to the best advantage; but the ease with which the fixation action is evoked with even minimal movements of the arm is very remarkable. It is possible that here we have one of those co-ordinated muscular reactions which were highly specialised for the purpose of tree-climbing, for the muscles which pass between the arm and the ribs are the great agents for pulling the body up to the hands as the animal climbs upwards. In this act the fixation of the ribs to the pelvis by contracted muscles is of the greatest importance, and the rapid response of these muscles when even trivial arm movements are performed

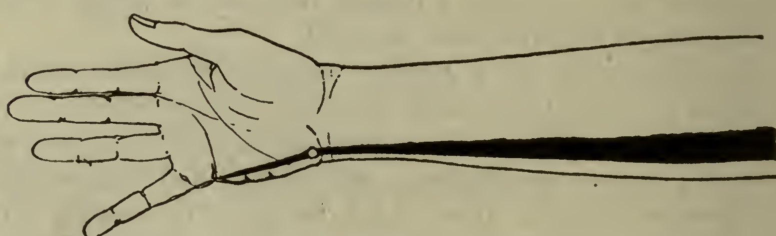

Fig. 78.—*Volition*—movement of the little finger towards the ulnar side. The flexor carpi ulnaris acts alone as a *Fixation muscle* for the abductor minimi digiti.

is, perhaps, reminiscent of the time when the act of pulling the body up towards the arms was one of the great functions of the costo-brachial group of muscles. Most muscles, therefore, may act as *prime movers*, *antagonists*, *synergics*, and *fixation muscles*, and every individual muscle is therefore called into play in many more voluntary acts than those which are usually ascribed to it when only its prime moving function is taken into consideration. A dentist knows that every tooth except the lower central incisor and the last upper molar engages the biting surfaces of two other teeth, and that its importance in mastication is therefore greater than that pictured by the layman, who regards it merely as one member of a series comprising thirty-two individual units. The loss of a single tooth not only deprives the series of one member, but it impairs the action of two other members. The medical man should in the same way regard

a muscle as a more important structure than a mere contracting element which produces one definite action, for the loss of a muscle is felt not only because its prime moving action is gone, but because muscles performing several other actions share in the loss of a member, which assisted their actions as an antagonist, a synergic, or as a fixation muscle.

These are the normal actions of muscles. A word is necessary concerning abnormal actions. Since only movements are represented cortically, it follows that, if the brain desires the performance of a certain action, any muscle which can possibly be persuaded to produce this movement is liable to be called into action. If the prime movers of the desired action are paralysed, then an attempt will be made with any available muscle to reproduce this action, or one which is as nearly as possible a substitute for it. In this way the most unexpected muscles may be trained to produce movements the proper prime movers for which have ceased to act. This is a most important fact from two points of view. In the first place, a patient who has a real paralysis following nerve injury may educate other muscles, whose nerve supply is intact, to perform movements which are so similar to those actually produced by the paralysed muscles that the observer, who is not on his guard, may be very easily deceived. In the second place, the so-called re-education of movements in patients recovering from nerve injuries is an exceedingly exacting business, and one that should not be undertaken by persons not thoroughly acquainted with the actions of individual muscles. It may well happen that re-education leads to nothing more than the cultivation of trick movements by muscles that were never paralysed, for it is often far more easy to teach the patient these tricks than to persuade him to exercise muscles the use of which he has not had for some considerable period. These trick actions of muscles can only be appreciated by actual experience, but the more important of them will be noted in their proper place.

CHAPTER XVI.

The Extrinsic Muscles.

In dealing with the muscles which act upon the hand it is customary to divide them into two sets, known as the extrinsic and intrinsic groups.

The extrinsic muscles are those which pass to the hand from the arm or forearm, and the intrinsic muscles are those which in their whole length are confined to the hand itself. The extrinsic muscles are, therefore, long muscles, and the intrinsic muscles are short muscles. This is a convenient form of subdivision, and it will be adopted here, but it must be remembered that for the purposes of comparative anatomy such a classification is not of universal application, for what in one animal is an intrinsic muscle may be in another an extrinsic one.

The extrinsic muscles are flexors and extensors, the one set bending the parts towards the ventral surface of the body, or towards the ground in the position of the primitive animal, and the other set straightening them back again from this bent position. The flexors and extensors act both upon the fingers and the hand, the one group bending and straightening the fingers and the other group bending the hand to and from the ventral aspect at the wrist joint. This last set of muscles—the flexores and extensores carpi—will be passed over without entering into much anatomical detail.

Of the benders of the hand at the wrist joint there are two, the flexor carpi ulnaris and flexor carpi radialis, both of which arise upon the ulnar condyle of the humerus, but which are inserted upon the ulnar and radial borders of the hand respectively. Some general lessons may be learned from these muscles without an unnecessary discussion of those precise facts of their anatomical disposition which are set forth in every text-book of anatomy. First, it is necessary for the student of anatomy, if the knowledge which he gains in the dissecting room is ever to

be turned to practical account, to become familiar with the typical appearance of muscles and tendons, so that he may recognise them by their own individual characters when he exposes them on the operating table. No better example could be had than that furnished by the flexors of the wrist, for there is no chance of mistaking the ulnar flexor for the radial flexor when once their characters have been appreciated. The radial flexor is a round fleshy muscle in the upper part of the forearm; but a little way below the mid-point of the forearm it becomes a rounded, clean, and shining tendon altogether devoid of muscular fibres. The flexor carpi ulnaris, on the other hand, is a flattened muscle which always continues with fleshy fibres upon the ulnar side of its tendon as far into the hand as the pisiform bone. One glance is enough to distinguish these two tendons, and render their identity absolutely certain.

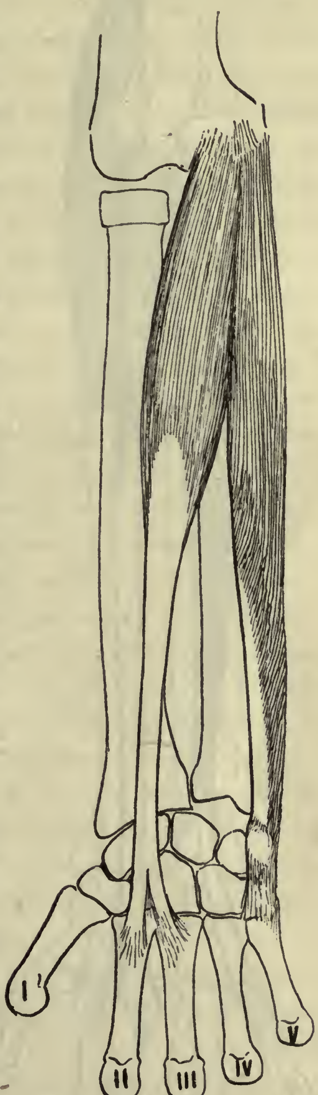

Fig. 79.—The flexor muscles of the wrist joint.

Although there are two flexors of the hand, one inserted on the ulnar side and the other on the radial side, there are three extensors: the extensor carpi ulnaris, the extensor carpi radialis longior, and the extensor carpi radialis brevior. There are therefore two radial extensors to balance the action of a single radial flexor. The extensors of the wrist arise upon the radial condyle of the humerus and are inserted into the bones of the hand. The tendon of the extensor carpi ulnaris is attached to the dorsal surface of the base of the metacarpal bone of the minimus,

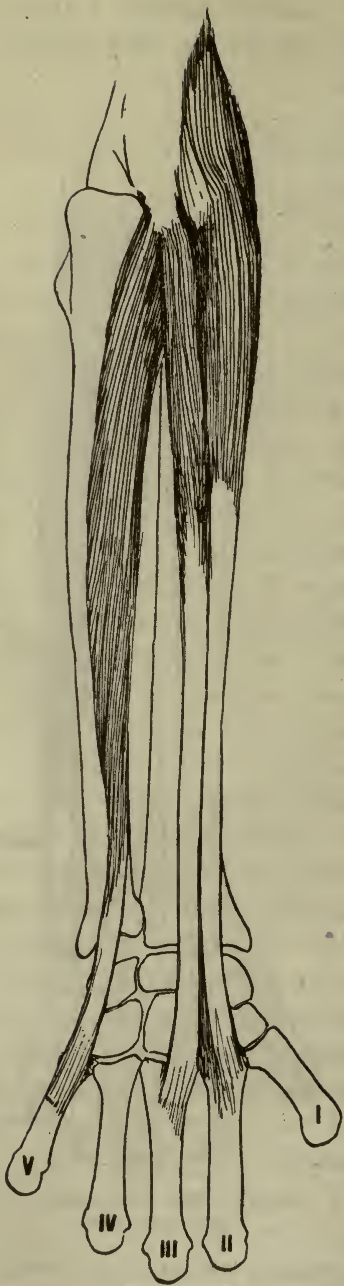

FIG. 80.—The extensor muscles of the wrist joint.

and to counteract its pull the tendon of the flexor carpi ulnaris passes to the palmar surface of the same bone by way of the pisiform. These two muscles therefore pull directly against each other on opposite sides of the base of the metacarpal of minimus. But the extensor carpi radialis longus is inserted into the base of the dorsal surface of the index metacarpal, while the tendon of the extensor carpi radialis brevis is fixed to the similar area on the metacarpal of medius. In order to counteract the pull of these two muscles upon the separate bones, the tendon of the single flexor carpi radialis splits, and part is inserted to the palmar surface of the base of the index metacarpal, and part to the corresponding site on the metacarpal of medius. This is, therefore, a good example of one muscle acting as the opponent to two separate muscles and producing an effective opposition by a complication of its tendon; and as such it illustrates a general principle of the functional arrangement which prevails throughout the body.

The flexor carpi ulnaris, passing from the ulnar condyle of the humerus to the palmar surface of the base of the metacarpal of minimus, acts (1) as a prime mover, and in company with the flexor carpi radialis, in the movement of

flexion of the hand upon the forearm; (2) as a prime mover, and in company with the extensor carpi ulnaris, in the movement of pulling the hand towards the ulnar side; (3) as an antagonist to the extensor carpi ulnaris when this muscle extends the hand at the wrist joint; (4) as an antagonist to the extensor ossis metacarpi pollicis when this muscle pulls the hand towards the radial side; (5) as a synergic to the extensor ossis metacarpi pollicis to prevent this muscle pulling the whole hand in a radial direction when abduction of the thumb is the desired action; (6) as a synergic with the flexor carpi radialis to the extensor muscles of the fingers to prevent the backward bending of the wrist which would otherwise be produced by these muscles; (7) as a special fixation muscle of the pisiform for the action of the abductor muscle of the little finger; (8) as a fixation muscle with the other muscles acting on the wrist joint to steady the wrist during the execution of fine finger movements. (9) Since it passes across the flexor surface of the elbow joint, it may possibly act in an abnormal manner as a flexor of that joint when the hand is supinated; but the conditions under which its cultivation for that purpose would be necessary must be rare.

From this analysis of the actions of the flexor carpi ulnaris the functions of the other muscles acting on the wrist joint may readily be deduced, and they need therefore not be stated with any unnecessary detail. The extensor carpi ulnaris acts (1) as a prime mover in extending the wrist, and in moving the hand towards the ulnar side; (2) as an antagonist to the flexor carpi ulnaris and to the extensor ossis metacarpi pollicis; (3) as a synergic to the extensor ossis metacarpi pollicis and to the flexors of the fingers; (4) as a fixation muscle.

The radial flexor and extensores carpi are prime movers for flexion and extension of the wrist and synergics to the extensors and flexors of the fingers; but they do not, as a rule, produce radial deviation of the hand, this action being produced by the extensor ossis metacarpi pollicis. When the hand is held pronated the extensores carpi radiales may assist the supinator longus in flexing the elbow joint, an irregular action which may be cultivated when the biceps and brachialis anticus are paralysed.

For our present purpose the extrinsic muscles which act upon the fingers are of more immediate importance. These muscles are the long flexors and extensors. The long flexors are arranged in two layers, a superficial layer and a deep layer, the two layers being commonly connected to each other by some fleshy fibres passing between them. The superficial layer constitutes the *flexor digitorum sublimis* or flexor perforatus, names which respectively denote the superficial position of the muscle in the forearm, and the fact that its tendons are perforated in the hand by the tendons of the deep flexor. But the name of the flexor secundi internodii digitorum manus, which was used by Cowper, although somewhat cumbersome and one that has generally passed into disuse, has much to recommend it as an accurate designation of its precise *rôle* in the action of flexing the fingers.

The flexor digitorum sublimis arises from the ulnar condyle of the humerus by means of the fibrous tissue septa which are common to it and to the fibres of origin of the other flexor muscles. Passing downwards, its fibres gain origin from the ulnar side of the capsule of the elbow joint. By way of this ligament its fibres of origin next arise from the inner side of the coronoid process of the ulna, a definite tubercle usually indicating the site of origin upon the bone. Next, the muscle gains origin by fibres which unite it to the lower part of the tendon of the brachialis anticus as this tendon gains its insertion into the coronoid process.

The origin of the muscle now passes across the forearm from the ulna downwards and outwards to the radius. In the interval between the two bones the muscle is slung from a fibrous arcade, which passes from bone to bone superficial to the deep flexor muscles. Under this arcade the median nerve and the ulnar artery and veins pass in order to enter the intermuscular cleft between the two strata of digital flexors. From the radial extremity of the fibrous arcade some fibres are usually given off to join the deep flexor layer. One such set of connecting fibres commonly unites the superficial flexor to the special flexor of the thumb, and these fibres have even risen to the dignity of possessing a separate name, being sometimes known as musculus accessorius ad flexorem profundum digitorum (Gantzer). On

the radius the muscle has an extensive origin from the oblique line, and over this portion of the muscle the radial artery runs.

From this extensive origin arises a bulky muscle which is almost hidden from view in the undissected arm by the more superficially placed pronator radii teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris. Between the flexor carpi ulnaris and the palmaris longus a portion of the muscle usually comes to the surface, so that the tendons of the flexor sublimus are visible in the lower part of the forearm. When the palmaris longus is absent this exposure is considerably increased.

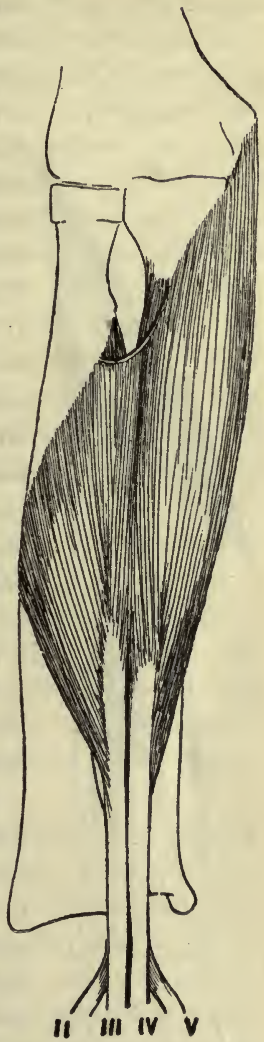

Fig. 81.—The flexor digitorum sublimis, superficial layer.

The flexor sublimus digitorum is a very characteristic muscle, and the arrangement of its fibres and tendons is remarkable. Looking at the surface of the muscle, one sees a large and rounded fleshy belly which shows a median division into two lateral parts, each part giving rise to its own tendon. Moreover, each lateral half tends to be more or less cleft in the middle line by the muscular fibres converging from either side and forming a bipenniform muscular mass. The radial half of the muscle is constituted of fibres running from the radius and fibres running from the fibrous arcade, and the ulnar half of fibres running from the fibrous arcade and fibres running from the ulna. The fibres of the radial half of the muscle converge on the tendon to medius, and the fibres of the ulnar half of the muscle converge on the tendon to annularis. The tendons which go to index and minimus come from a very distinct portion of the muscle which is hidden altogether from view by

the part which has just been described. The deep portion of the muscle is liable to considerable minor variations, and hardly any two subjects will show this muscle in an exactly similar form. It is connected to the superficial portion by variable fibres which are often dissimilar upon the two sides of the body. The flexor sublimis of the index and little fingers arises beneath the general mass of the muscle from the common tendon origin on the ulnar condyle of the humerus. The fusiform fleshy belly which springs from this origin gives rise to a short tendon near to the middle of the forearm, and from this tendon arise two secondary fleshy masses which terminate in tendons for the index and minimus respectively. This deep trigastic portion of the muscle appears to be mainly devoted to the index finger, for the secondary fleshy belly and tendon destined to pass to minimus are small. The tendons for index and minimus arising from the deep portion of the muscle pass into the palm of the hand immediately deep to the tendons of medius and annularis.

Fig. 82.—The flexor digitorum sublimis, deep layer.

The very beautiful arrangement of the perforated tendons of the flexor sublimis can only be appreciated when the flexor profundus has been described, and the precise arrangement will therefore be studied later; but meanwhile the site of their insertion is clear enough. The four tendons radiate from each other in the palm of the hand, and one tendon goes to each of the four fingers, there being no flexor sublimis tendon to the thumb. Each tendon splits at its insertion and joins the roughened edges of the palmar surface of the middle phalanx, and upon this phalanx the muscle exerts its action. When the flexor sublimis contracts as a prime

mover it flexes the middle phalanx on the proximal one at the proximal interphalangeal joint. It has no action whatever on the terminal phalanx, and in normal conditions it does not act upon the proximal phalanx. Its action as a prime mover is extremely specialised, for although it is anatomically capable of producing flexion of the wrist joint, its employment in producing these movements cannot be considered as part of its normal functional *rôle*. The passive condition of the long flexors during flexion of the metacarpo-phalangeal joints may be demonstrated by a simple test. If a finger be held with the two terminal joints acutely flexed, but the metacarpo-phalangeal joint extended, it will be found quite easy to flex the metacarpo-phalangeal joint while the two terminal joints are being actively extended. When the two terminal joints are being actively extended the long flexors are necessarily ceasing to contract, and it is obvious that the flexion of the metacarpo-phalangeal joint is being produced by some other muscle. More than this, Duchenne insisted upon the absolute inability of the long flexors to produce this movement, and the results of paralysis of the proper flexors of the metacarpo-phalangeal joints show this teaching to be true. For the purpose of a practical application of anatomy to the study of living people we should therefore modify the teaching of most of our text-books, and omit flexion of the metacarpo-phalangeal joints as one of the normal actions of the flexor sublimis digitorum.

The action of the long flexors of the fingers upon bending the wrist joint, although included by most anatomists as part of the normal *rôle* of these muscles, needs some consideration. When we flex the fingers with the long flexors it will be noticed that the extensors of the wrist come into action. This contraction of the extensors is generally regarded as being evidence of synergic action on the part of these muscles, and it is assumed that they come into play to prevent the flexors of the fingers wasting their energy in producing a flexion of the wrist. No doubt this assumption is in part warranted, but it must be noted that when forcible efforts are made to flex the wrist against resistance, the flexors of the fingers take so little part in the action that they may be actively extended without

diminishing the force employed in flexing the wrist. The action of the extensors of the wrist in the effort to forcibly flex the fingers appears therefore to differ in some ways from that usual in synergic muscles. It is notorious that the grasp of the fingers is more powerful when the wrist is extended than when it is flexed; and this is merely an example of a principle which prevails in the muscular mechanism of all Vertebrates, for the action of the extensors of the wrist puts the flexors of the fingers on the stretch. If the fingers are all extended, and then the extensors of the wrist are brought into play without any regard being paid to the behaviour of the fingers, it will be noticed that the digits tend to flex into the palm by the mere passive stretching of their flexors. In many arboreal animals extension of the wrist and elbow joints produces automatic flexion of the fingers without any active contraction of the flexors being involved. In this way the animal is able to suspend itself from its flexed digits with a minimum of muscular effort. Exactly the same condition is seen in the human hand in cases of contracture of the flexors, for when this has occurred the patient cannot straighten out the fingers when the wrist is extended. The contraction of the extensors of the wrist during flexion of the fingers is, therefore, not a simple synergic action in the sense in which this action is defined here, and it must, therefore, not be assumed to indicate that the flexors of the fingers are necessarily flexors of the wrist joint.

The other extrinsic flexor of the digits is the *flexor digitorum profundus*, which, since its tendons perforate those of the superficial flexor, was called flexor perforans by Douglas, and by Cowper was termed flexor tertii internodii digitorum manus from its action. This muscle has an extensive origin from the flexor aspect of the ulna, from a fibrous expansion which, common to it and the flexor and extensor carpi ulnaris, is attached to the inner side of the ulna; from the interosseous membrane between the ulna and the radius; and from the radius itself by a few fibres attached below the tuberosity. Another portion of the same sheet of muscle arises from the flexor surface of the radius, and this is known as the *flexor pollicis longus* or flexor tertii internodii pollicis. This muscle usually

has some fibres connecting it to the superficial flexor as well as some which arise from the coronoid process of the ulna. In the whole muscle mass of the deep flexor of the digits three distinct parts may be noted: (1) a part which arises from the ulna; (2) a part which arises from the interosseous membrane; (3) a part which arises from the radius. The first part gives rise to three tendons in the palm of the hand, and these tendons pass to minimus, annularis and medius; the second part gives rise to its tendon in the forearm, and is destined for the index; the third part also develops a tendon in the forearm, and is inserted into the thumb. Each of these tendons is inserted into the base of the palmar surface of the terminal phalanx of its respective digit, and in order to reach this insertion it has to perforate the corresponding tendon of the superficial flexor where, as in the case of index, medius, annularis, and minimus, this tendon is present.

FIG. 83.—The flexor digitorum profundus and the flexor pollicis longus.

The anatomical arrangement by which this is permitted is a very beautiful one. In the palm of the hand the tendons of the deep flexor lie immediately beneath those of the superficial flexor, and towards the base of the finger the superficial tendons become flattened against the deep tendons. A groove is formed upon the middle line of the flattened tendon, and towards the middle of the basal phalanx each tendon splits, and each lateral half passes round the side of the deep tendon, so that the two halves meet again behind the tendon. In their passage round the deep tendon the two portions of the split superficial tendon undergo a spiral twisting, so that the edges which were medial on the surface become lateral behind the deep tendon, and the surface, which was next the skin before the tendon was perforated, becomes turned against the bone after the two halves have reunited behind the

deep tendon. The reunion takes place towards the distal end of the proximal phalanx, and the junction consists of more than a mere union of the edges of the two halves of the split tendon. Opposite the proximal interphalangeal joint some of the fibres of one half of the tendon pass across the middle line and join the other half of the tendon, a real interdigitation of fibres taking place at the junction. This interdigitation is sometimes known as the *chiasma tendinosum* of Camper. After having formed the chiasma the two halves of the tendon separate again and are inserted to the ridges on the sides of the middle phalanx. It thus comes about that each half-tendon becomes completely reversed, and that much of the right half of each tendon is inserted to the left side of the phalanx. Through the tunnel formed by the split tendon of the flexor sublimis the tendon of the flexor profundus passes on, and crossing the distal interphalangeal joint, is inserted into the base of the terminal phalanx. This arrangement of the tendons of the flexors of the digits is an extremely beautiful piece of mechanism, and is an instance of the universal rule that tendons need to be bound down by slings over joints which they are capable of bending. The flexor sublimis acts as the sling for the flexor profundus in a manner to which further attention will be paid later on.

Like the flexor sublimis, the flexor profundus is a muscle of very specialised function. Acting in the normal way as a prime mover, it flexes the terminal joints of the digits; it can also assist in the flexion of the medial phalanx; but the criticisms which we have applied to the accessory actions ascribed to the flexor sublimis apply also to this muscle. The action of the flexor profundus upon the medial phalanx is a good deal less than would be gathered from the anatomical arrangement displayed on dissection. When the flexor sublimis is paralysed, the action of the flexor profundus upon the medial phalanx is very easily detected, for flexion takes place by a process best described as "winding up" the finger, the terminal joint being flexed fully before the medial joint is bent.

It should be noted that when the fingers are separated from each other, and the long flexor muscles are brought into action, the fingers not only flex, but their tips tend to be drawn

together as they close towards the palm. In the ordinary action of closing and opening the hand the fingers tend to come together and to spread apart as they are flexed and extended. There are special intrinsic muscles (the interossei) for spreading the fingers apart and for closing them together side by side; but, in the absence of the action of these muscles through paralysis, the flexors and extensors may produce movements which simulate those normally carried out by the interossei.

The flexor pollicis longus acts in direct opposition to the extensor pollicis longus and flexes the terminal joint of the thumb, and, like the flexor profundus to the other digits, it is capable of producing flexion of the proximal joint, but this only to a very limited extent.

Like the extrinsic flexors, the extrinsic extensors of the digits are arranged as a superficial layer and a deep layer. The superficial extensor mass comprises the *extensor digitorum communis* and the *extensor minimi digiti proprius*, or extensor auricularis. The extensor communis arises from the radial condyle of the humerus in common with the extensor muscles of the wrist, and also to a very large extent from the fibrous tissue which is interposed between and wrapped around these muscles. The extensor minimi digiti can only be said to arise from the fibrous tissue and from the extensor communis, for an artificial dissection is needed to effect a complete separation of these muscles as they are traced up to the radial condyle of the humerus. The extensor minimi digiti has not always been admitted in human myology to rank as a separate muscle, many of the older anatomists regarding it merely as a portion of the common extensor. Its degree of separation from the common extensor varies, but, as we shall see later, the question of its belonging to the superficial layer or extensor sublimis, or the deep layer or extensor profundus, is one of some uncertainty. Of the common extensor mass the portion destined for the index finger is usually the most distinctly segmented off, and often its fleshy belly is separated from the rest of the muscle in the middle of the forearm. The part which goes to medius is the largest portion of the whole mass, whilst that for minimus is the smallest,

and muscular fibres are continued into its tendon as low down as the wrist. Each of the four tendons passes across the wrist, and they are visible and palpable upon the back of the hand. On the backs of the metacarpal bones the tendon to annularis often splits into two, and from the sides of the separated tendon expansions run to join the tendons of medius and minimus. At times the tendon of annularis divides imperfectly into three portions, of which the central part is continued to its own (fourth) digit while the two side parts run to the tendons going to minimus and medius. Again, in some cases the tendon remains single and sends fibres from it's sides to join the neighbouring tendons. Not at all uncommonly the extensor communis sends no tendon to the little finger, and in this case an expansion from the tendon of annularis joins the tendon of the extensor minimi digiti. These lateral expansions are known as the *vincula accessoria*, and their movements beneath the skin of the back of the hand, when the independent extension of a single finger is attempted, are familiar. A band of a similar nature, but usually very much less well defined, sometimes runs transversely between the tendons of index and medius. When each tendon has reached its respective metacarpo-phalangeal joint it sends off from its sides broad bands of fibres, which, running at right angles to the course of the tendon, pass between the heads of adjacent metacarpal bones and wrap round the sides

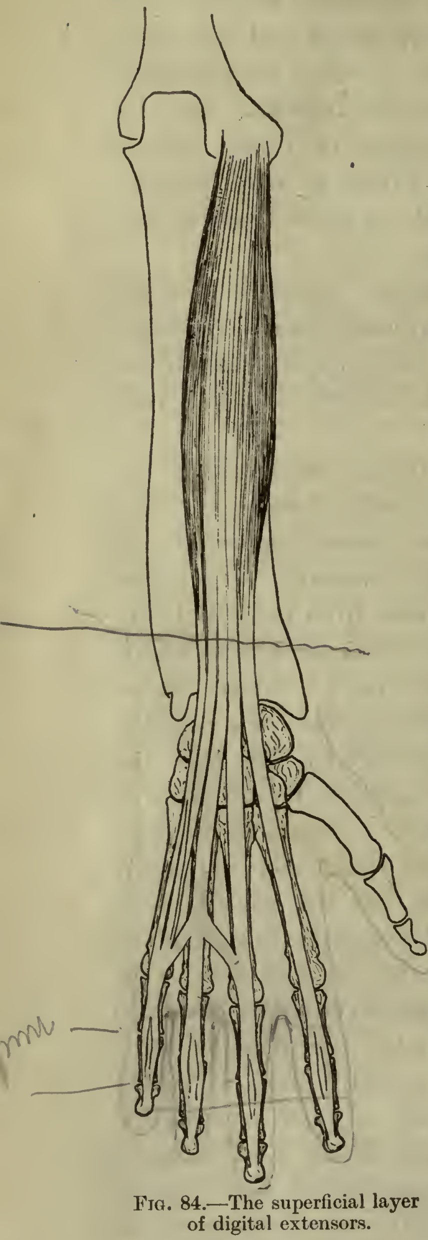

Fig. 84.—The superficial layer of digital extensors.

of the joint to form a part of the capsule of the articulation. Having given off these expansions, the tendon is fixed by a band from its deep surface to the base of the proximal phalanx. The tendon now broadens and becomes split into three portions. The central portion runs onwards and becomes inserted into the base of the middle phalanx. The two lateral portions, to which the expansions of the tendons of the interossei and lumbricales are also united, run on and reunite at the base of the distal phalanx where they are inserted.

The tendon of the extensor minimi digiti very commonly splits into two upon the back of the hand, and, after having joined with the small tendon which the common extensor sends to the little finger, it behaves in the manner typical of the other tendons.

Like the extrinsic flexors, the extensor communis has a highly specialised action upon the digits, and there is no doubt whatever that its principal function as a prime mover is to extend the metacarpo-phalangeal joints. When these joints are actively extended the muscle may easily be felt to contract, and when the muscle is paralysed the power of straightening the fingers at the metacarpo-phalangeal joint is lost; but the remaining two joints may be extended by other muscles. If we extend our fingers at the metacarpo-phalangeal joints by the forcible contraction of the extensor communis, we are still free to flex the fingers at the two interphalangeal joints; and if we flex our metacarpo-phalangeal joints fully, we may still extend the remaining joints of the fingers. These facts are commonly assumed to prove conclusively that the extensor communis has no action upon the two terminal phalanges; but this assumption is not absolutely correct. When all the other muscles which can extend the two terminal phalanges are paralysed, but the extensor communis remains functional, it will be found that some extension of these phalanges may be produced when the fingers are flexed. The extensor communis, acting alone, cannot pull a finger perfectly straight; its selective action is on the metacarpo-phalangeal joint, but nevertheless it is capable of acting on the other joints to a lesser extent when the metacarpo-phalangeal joints are very slightly flexed.

The action of the extensor communis in producing a spreading

apart of all the fingers has already been mentioned in connection with the opposed action of the flexors. In this respect the extensor minimi digiti is worthy of special notice, as it acts as a very important abductor of the little finger.

The action as an extensor of the wrist joint, though usually included among the functions of the extensors of the digits, is extremely slight.

The deep layer of extensors, the extensor digitorum profundus, is extremely reduced in Man. Four muscles definitely belong to this group, three of them being attached to the thumb and one to the index finger. The thumb muscles are named—(1) *Extensor ossis metacarpi pollicis,* the term in most general use, Abductor longus pollicis (Albinus) or Extensor primi internodii pollicis (Douglas and Cowper); (2) *Extensor pollicis brevis,* also commonly known as Extensor primi internodii pollicis (Innes) or Extensor secundi internodii pollicis (Douglas and Cowper); (3) *Extensor pollicis longus,* also commonly known as Extensor secundi internodii pollicis (Innes) or Extensor tertii internodii pollicis (Douglas). The muscle derived from the extensor profundus which goes to the index finger is known as *Extensor indicis proprius* (Winslow), or indicator.

The *extensor indicis proprius* is the shortest muscle of the group, and it arises from the extensor surface of the ulna and slightly from the interosseous membrane between ulna and radius. Fleshy fibres arise from the ulna for a variable distance below the middle of the bone, and the tendon is formed just above the wrist joint. It is inserted with the index tendon of the extensor communis digitorum in the manner described above, for over the metacarpo-phalangeal joint the special tendon loses its identity by blending with the ulnar side of the common tendon.

The *extensor pollicis longus* arises from the extensor surface of the ulna immediately above the extensor indicis proprius and also slightly from the interosseous membrane and from the fibrous tissue between it and the extensor carpi ulnaris. From this origin the fleshy fibres converge in a bipenniform manner upon a tendon which is formed upon the posterior surface of the muscle. Fleshy fibres pass to either side of this tendon as far as

the lower end of the radius, where the tendon, becoming bare, grooves the radius, and turning towards the base of the thumb, runs as a conspicuous cord along the dorsum to be inserted into the base of the terminal phalanx. This tendon forms the well-marked ridge which constitutes the ulnar boundary of the so-called "anatomical snuff-box." The *extensor pollicis brevis* arises from the interosseous membrane and from the extensor surface of the radius below its mid-point, and it is overlapped at its origin by the other muscles of this group. Its tendon is formed over the lower end of the radius, and running in company with the tendon of the next muscle, it forms the radial boundary of the "snuff-box." The tendon passes along the dorsum of the thumb, and is inserted into the base of the proximal phalanx.

The *extensor ossis metacarpi pollicis* is a strong muscle which arises from the extensor surface of the ulna above the origin of the extensor pollicis longus and below the attachment of the supinator brevis, from the interosseous membrane, and from the extensor surface of the radius above the origin of the extensor pollicis brevis and below the attachment of the supinator brevis. The muscular fibres converge on a flattened tendon which passes in company with the tendon of the extensor pollicis brevis on the dorsum of the thumb, and is inserted into a tubercle upon the radial side of the base of the metacarpal bone, and also to a corresponding

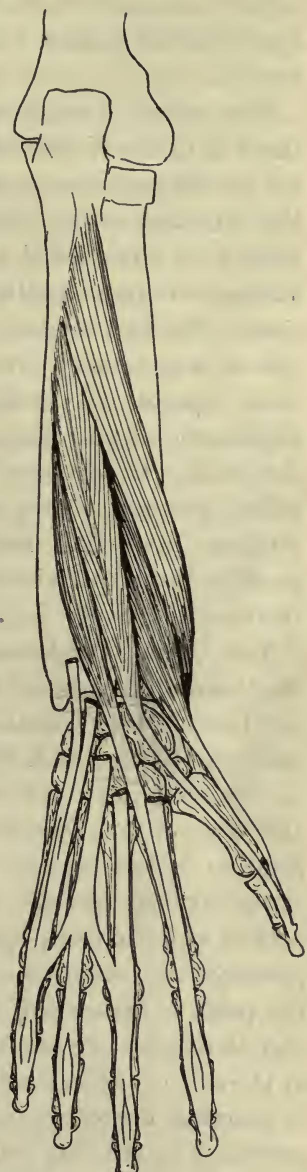

Fig. 85.—The deep layer of digital extensors.

tubercle upon the trapezium. As will be noted later on, a slip from the tendon of the extensor ossis not infrequently passes to the abductor pollicis brevis, one of the intrinsic muscles of the thumb.

The actions of the deep extensors are somewhat complex, since three of them are inserted to the thumb, thereby obtaining scope for producing more varied movements than those permitted to the extensors of the other digits. The *extensor indicis proprius* cannot be dissociated in its action as an extensor from the extensor communis attached to the same finger, since the insertion of the two tendons is made in common. By Douglas the muscle was termed extensor secundi internodii indicis, and in some animals the independence of its tendon warrants the application of that name, but in Man its differential action does not exist. In one very curious action, however, the extensor indicis proprius shows remarkable independence, for when the intrinsic adducting muscles of the fingers (interossei) are paralysed, the special extensor of the index can still adduct it to the medius.

The *extensor pollicis longus* extends the terminal phalanx of the thumb. To a lesser degree it also extends the basal phalanx on the metacarpo-phalangeal joint. In addition to this, it has, owing to the ulnar-sided pull of its tendon, the power of rotating the whole thumb so as to bring its nail directly to the dorsal surface and range it thus alongside the index finger. This movement of rotation is done as the opponent of the opponens pollicis, one of the intrinsic muscles. It is this action of the extensor longus pollicis which in cases of paralysis of the opponens and adductors produces the condition sometimes termed "ape hand," in which the palm is broadened, the palmar surface of the thumb faces almost directly forwards, and the thumb is brought into line at the side of the index finger. This action is an important one in practical neurology, and it is necessary to realise that it is produced by the long extensor of the thumb. It is often taught that this position of the thumb is brought about by the adductor pollicis (Athanassio-Benisty, etc.), but its production is typical of conditions in which this muscle is paralysed. The long extensor is also able, by its pull upon the thumb, to move the

whole hand to the radial side and to pull it in a dorsal direction. In the normal way this movement is prevented by the synergic action of the flexor carpi ulnaris. The *extensor pollicis brevis* extends the basal phalanx at the metacarpo-phalangeal joint and also abducts the thumb, or pulls it to the radial aspect without producing any rotation of its metacarpal bone. Despite its name, the extensor brevis is the only direct abductor of the metacarpal of the thumb. The *extensor ossis metacarpi pollicis* is a very curious muscle. It abducts the thumb, and it is also a powerful abductor of the hand; that is, it pulls both thumb and hand towards the radial side in direct opposition to the flexor and extensor carpi ulnaris, acting together. But it also possesses two very deceptive actions. It can pull the metacarpal bone of the thumb and the trapezium in a palmar direction, and this action when combined with contraction of the adductor pollicis may produce a movement which simulates true opposition of the thumb. It is possible that in some cases, in which most perfect opposition of the thumb is produced in cases of median nerve paralysis, the slip which often unites the tendon of the extensor ossis metacarpi pollicis to the abductor pollicis brevis assists in producing the deceptive action. Again, in the absence through paralysis of the two flexors of the wrist joint, the extensor ossis metacarpi pollicis may flex the hand on the wrist with some considerable force.

CHAPTER XVII.

THE MORPHOLOGY OF THE EXTRINSIC MUSCLES.

THE study of muscles in practical anatomical work is made interesting for some students and rendered irksome for others by reason of the frequent departures from the text-book ideals which are met with in the course of dissection. Human muscles are subject to numerous variations. Here a muscle will be found arising in an abnormal manner, and here inserted to a somewhat different area from that which is usual. At times the muscle subdivides into more or less definite minor entities; at times it is lacking altogether or partly blended with a neighbour. A normal muscle may be abnormally developed or disposed, or an abnormal muscle may make its appearance and exist as an addition to the usual complement of muscles of the part. For the older anatomists these variations were merely interesting freaks and evidences that all men were not alike even in the hidden details of their internal anatomy. But after the publication of Darwin's work muscular anomalies assumed an altogether different importance. Variation and natural selection were the key-notes of Darwin's work, and the search for human variations became a keen one. Variable muscles were eagerly reported, books were kept in all dissecting rooms for their recording, and the literature of the anatomical journals became a great repository of accounts of muscular anomalies. This activity was brought about by the stimulus attaching to the business of determining the trend of variation. A muscle which appeared as an occasional variation in Man might turn out to be a normal muscle in some other animal, and one might thus determine the ancestor from which we had inherited this legacy. This is, of course, a perfectly logical procedure, and when conducted with scientific restraint is capable of attaining a great deal of real phylogenetic probability. But enthusiasm has often outrun restraint in these inquiries, and the present science

known as morphology contains quite an unusual amount of unsound building material in its foundations. Many of the tags of comparative anatomy which pass current in the curriculum of our medical schools are the uncriticised remnants of this period of enthusiasm. Abnormal muscles in Man are compared with more or less similar muscles which are normal in birds, horses, highly specialised reptiles, and a host of creatures unrelated to the line of the human stock. As a result of a long study of anatomical variations Professor Macalister made this position clear in the Robert Boyle Lecture of 1894: "I cannot see that when one finds in the limb of a kangaroo or of a sloth, or in the face of a horse, a certain form of muscle like one which occurs as an anomaly in Man, we must therefore conclude that its human occurrence must therefore be due to atavism. Indeed, the more I survey the catalogue of such parts, the more I am impressed with the failure of the method as a scientific mode of accounting for these anomalies, while at the same time I am filled with admiration at the industry and ingenuity with which the process of matching has been carried on."

The late Professor Dwight, of Harvard, was a profound student of human variations, and even if his very deep convictions may for some argue bias in his criticisms, the justice of his strictures on this phase of morphology is not to be denied. "To find an occasional form of a muscle in Man that is normal in no matter what animal was apparently perfectly satisfactory and profoundly scientific. It was of no consequence to what species, order, or class the animal might belong. In the case of the biceps alone were found instances of the arrangement peculiar to enough animals to stock a menagerie. The ornithorhynchus did just as well as an ape, and a giraffe as a monkey; to find an instance of similarity was all that was required. How the peculiarity could have been transmitted to Man was passed over" ("Thoughts of a Catholic Anatomist," 1911, pp. 208, 209). Since it is to be presumed that we have now passed beyond this period into one which is marked by a rather more critical attitude, there is no need to labour this point. But there is still much work to be done before we can be said to have sifted the grain from the chaff which has accumulated during the past

half-century. For this reason any study of the morphology of the muscles of the hand must needs be written and read with a full consciousness that the subject is a somewhat speculative one, and that its doctrines should be tested by every student of anatomy whenever the opportunity to do so presents itself.

As for the flexors and extensors of the wrist there is little to be said. They are a primitive set of vertebrate muscles which retain in Man all the essential features of their basal simplicity. The radial extensors are the most subject to variation. The two muscles may be variably blended or unduly subdivided. Two additional slips are of sufficient frequency to have been given names (by Wood). These are the *Extensor carpi radialis intermedius* and the *Extensor carpi radialis accessorius*, of which the latter is usually distinguished by its deep position and the insertion of its tendon to the carpal or metacarpal of the first digit. Of the palmaris longus, the ancient flexor of the metacarpo-phalangeal joints, we have already made some mention in connection with the fascia derived from its degenerated tendons. The long flexors and extensors of the digits are muscles which present a far greater number of variations than do the flexors and extensors of the wrist joint, and some lessons derived from a study of these variations seem definite enough in their meaning. In the first place, it is to be noted that the first digit both upon hand and foot, being short of one of its bony segments and one of its joints when compared with the rest of the digits, does not require so many flexors as are necessary for the other digits. For the thumb and big toe only one long flexor and one short intrinsic flexor are needed, whereas for the other digits two extrinsic and one intrinsic flexor are required to produce a proper flexion of all the joints. Both in the fore and hind limbs the superficial digital flexor, arising from the bone of the first segment of the limb, fails to send a tendon to the first digit. The flexor digitorum sublimis of the human arm is a comparatively simple muscle manifesting an extremely primitive condition, and it is only necessary here to note the distinction of that portion of it which is destined to furnish the tendon to the index finger. But in the hind limb the superficial digital flexor has undergone a change in the majority of the mammalia. Primi-

tively arising from the fibular condyle of the femur, it passed into the sole of the foot, and was inserted into the second, third, fourth, and fifth digits in a similar fashion to the corresponding muscle in the fore limb. The portion of the muscle in the leg was a fleshy mass which passed from the fibular to the tibial side of the tendo Achillis as a tendon which divided into four separate tendons in the foot. Reduction of the fleshy belly in the leg, loss of continuity between it and the tendons in the foot with the development of a new set of muscular fibres in the sole, are the processes seen in varying stages in existing mammals. Concerning the portion which is left in the sole there is no doubt: it becomes the flexor digitorum brevis of human anatomy; but concerning the fate of the fleshy portion in the leg there is some difference of opinion. It is commonly taught by human anatomists that the soleus in the calf of the leg represents the flexor digitorum sublimis in the forearm. In many animals, however, a superficial digital flexor arising from the femur coexists with a soleus arising from the fibula; and it is difficult or impossible to see how, in the face of this fact, the homology can be sustained. An older teaching, and one advocated by Humphry ("Observations in Myology," 1872, p. 174), assumes the plantaris to be the divorced portion of the superficial flexor in the leg. Although this teaching necessarily destroys the practically universally assumed homology between the plantaris and the palmaris longus, there is every evidence at hand to demonstrate its truth. The plantaris and palmaris longus present so many points of similarity that it is at first sight difficult to believe that they are not homologous muscles, but the similarity is only of that superficial kind which muscles passing into phylogenetic decrepitude share in common. In reality the palmaris longus belongs to that most superficial stratum of the digital flexors which acts upon the metacarpo-phalangeal joints, and in the leg its representative is most probably incorporated in the external head of the gastrocnemius, showing its individuality only occasionally by the appearance of some accessory muscular slip, such as the so-called gastrocnemius tertius of Krause, or the additional head of a bicipital plantaris or plantaris superficialis. The palmaris longus is in manifest continuity with the palmar fascia,

which represents its old insertion to the bases of the proximal phalanges ; but the central portion of the plantar fascia, which undoubtedly represents a similar rudiment in the foot, most commonly shows some continuity with the tendo Achillis, in which we presume the homologue of the palmaris longus to be incorporated. The plantaris, on the other hand, is a degenerated portion of the second stratum of digital flexors, the tendons of which act on the proximal interphalangeal joints, and which are perforated by the deep flexor tendons. A plantaris muscle continuous with the flexor digitorum brevis tendons is present in generalised mammals of several orders ; and in these types, therefore, the flexor sublimis vel perforatus digitorum pedis is preserved as a continuous entity, and provides a perfect homologue for the flexor sublimis vel perforatus digitorum manus. Regarded as a higher mammal, however, Man may be said to have it as a distinction that he retains the proximal divorced portion of the primitive flexor sublimis in such a comparatively well-developed form as the normal plantaris, for in many animals the reduction has proceeded much further. Among the anthropoid apes the plantaris is altogether lacking in about half the Chimpanzees that have been dissected ; it has only once been recorded in the Orang-utan, and never in the Gorilla. In only some seven out of every hundred human subjects dissected does the plantaris fail to be developed. In this feature Man is therefore more primitive than the anthropoid apes, despite the specialisation of the human leg for the purposes of orthograde progression. In lower monkeys the plantaris is present, and in *Tarsius spectrum* it is especially well developed.

The deep digital flexor group of Man presents several peculiarities which are worthy of notice. In the first place, it is, as a rule, only slightly united to the flexor sublimis, although in many animals the blending of the two strata is considerable. In the second place, we have seen that in its typical human form it shows a definite cleavage into three divisions. One portion arises from the ulna and sends tendons to minimus, annularis, and medius; the second portion arises from the interosseous membrane and furnishes the tendon for index; and the third portion, which is more distinctly separated, arises from the

radius and gives rise to the long flexor tendon for pollex. The first two portions are grouped together as the *flexor digitorum profundus vel perforans*, and the third is named the *flexor pollicis longus*. The specialisation of the portion for the index finger is a distinctly human character, and as such exhibits a considerable range of variability. The factor underlying the differentiation of this portion is undoubtedly the human specialisation of the index, and it is simply an expression of the general trend which we have seen at work in bones and muscles alike in connection with the development of this very characteristically human digit. Such a variation from the primitive plan as is presented by this subdivision of the human flexor profundus has been termed a "progressive" variation, in opposition to the atavistic variation or reversion. If it truly be progressive, it is possible that the medical student of some future epoch will have to be acquainted with a muscle named the flexor profundus vel flexor tertii internodii indicis.

With regard to the separation of the radial portion as the flexor pollicis longus, every one who has read any of the literature of the comparative anatomy of Man and the anthropoids knows the statement that "the complete separation of the flexor longus pollicis is characteristic of Man" (Quain's "Elements of Anatomy," 10th ed., Vol. II., Part II., p. 228). But when this human character of separation is contrasted with the condition in other Primates, some caution must be exercised before we regard Man as possessing a new and advanced muscular characteristic, as this is usually assumed to be. In many animals, and probably in its primitive condition, the deep flexor is divided into an ulnar portion and a radial portion; in some animals (Lorisine Lemurs among the Primates) both radial and ulnar portions may send tendons to many digits. But when the radial digit is well developed and specialised the radial portion tends to concentrate more and more upon a single tendon to this digit. In other words, the flexor radialis is centred upon the pollex when this digit is well developed. This is the condition which is practically realised in *Tarsius spectrum*, and which is typical of Man. On the other hand, when the pollex becomes a reduced member of the digital series the tendon from the radial portion

to this digit tends to disappear. In the Orang-utan Langer, Fick, Bischoff, Huxley, Chapman, Primrose, and others failed to find any trace of a tendon from the flexor digitorum radialis to the thumb. In the Orang dissected by Hepburn, and in the one examined by Brooks, the radial portion sent a large tendon to the index and a small one to the thumb. In the Chimpanzee a small tendon to the thumb arising from the tendon to the index has been described by Huxley, Macalister, Hepburn, and others. In the Gorilla dissected by Hepburn the thumb tendon was represented only by fascia derived from the tendon of the index. At times even this is absent, or at times a mere thread of a tendon has been discovered on dissection (Bischoff). In the lower monkeys the pollex when present is provided with a tendon which arises from the common deep flexor mass, but in *Tarsius spectrum* the human condition is again practically realised in a separate muscle and tendon specially provided for the thumb. In the Primates the big toe is usually far better developed than the thumb, and it must be remembered that a separate *flexor longus hallucis* is always present, though, as in the case of the *flexor longus pollicis,* this muscle often sends tendons to other digits as well. When, therefore, we contrast Man with the anthropoid apes in regard to the evolution of the flexor pollicis longus, we must not forget, as is so often done, that the condition found in the anthropoids is one of degeneration from the primitive type, being the direct consequence of the diminution of the pollex, and that they have retained for their well-developed big toes what they have lost for their small thumbs, nor must we overlook the fact that the most primitive of the Haplorrhine Primates —*Tarsius spectrum*—presents a condition which is very nearly human.

We have already seen that in the extrinsic extensors of the digits, as in the flexor group, there is evidence that two distinct strata of muscles are present. Of these the superficial stratum is known as the *extensor communis vel sublimis digitorum,* and in Man it exists in its common mammalian form. The deep stratum is, however, reduced from its full expression, in which a separate tendon is provided for each digit. This reduction is in process in many members of the primate series. In some of

the common Old World monkeys (*Cercopithecidæ*) a tendon of the extensor digitorum profundus goes to index, medius, annularis, and minimus, thus, counting the specialised tendon to pollex (which will be treated later), furnishing the primitive five tendons. In the Gibbons tendons pass to index, medius, and annularis, in the Chimpanzee to index and annularis (Hepburn), to index only (Champneys, Wilder), or more commonly to index and medius (Macalister, Primrose, etc.). In the Orang index and medius seem constantly to be furnished with tendons from the extensor profundus. The Gorilla alone appears to have a single tendon to index or an extensor indicis proprius as a normal condition (Bischoff, Hepburn). These statements are made apart from any question as to the exact morphological position of the extensor proprius minimi digiti, for sometimes this muscle is included among the superficial and sometimes among the deep tendons. (For a discussion of this question see *Proc. Anat. Soc.*, Vol. XXII.) From a study of its homologue, the peroneus tertius, in the foot there would seem to be good reason to believe that it was in reality a member of the deep series. In the Orang-utan the extensor minimi digiti is not confined to minimus, but also sends a tendon to annularis, and therefore if we reckon this muscle as a part of the extensor profundus we may say that in this animal the full complement of deep tendons may still be preserved. In the foot of Man, as in the rest of the Primates, and in the primitive condition, the deep extensors are retained to all the digits in the form of the extensor digitorum brevis and —in Man—the peroneus tertius.

It must strike any one as a very curious thing that in the wonderfully mobile and pre-eminently useful hand of Man there has been a loss of muscles destined to effect movements of the digits. At first sight it seems strange that in non-mammalian vertebrates and in lower mammals (see Figs. 86 and 87, illustrating the condition in the cat) more muscles should act upon the digits, and that in our feet we should retain more muscles for the movements of our toes than we possess for the movements of our fingers. Possibly the explanation is to be found in the different *rôles* which the function of extension of the digits plays in the human hand and foot. When the primitive digitate extremity

is employed in its primitive function—that of clambering—the double set of finger flexors bends the fingers and obtains a grasping hold; then as the animal progresses forwards the extensors come into action, and the grasp is released. But, more than this, the extensors of the digits now begin to pull the second segment of the limb over the resting manus or pes. The muscles act from what in human anatomy is their digital insertion, the manus or pes becomes bent on the second segment at the wrist or ankle, and, finally, the digits themselves are angulated to the extensor aspect as the body moves forwards, and the member is raised free altogether from the surface over which the animal is progressing. The same sequence occurs in the movements of the human toes in the ordinary process of walking. First, the toes are flexed, so that they obtain a good grip of the ground; then, while the flexors are still acting, the extensors come into play, and acting from their insertions, they help to bend the ankle. Finally, as the body passes forwards, the toes become bent in a dorsal direction at the metatarso-phalangeal joints; the weight is borne on what is called the "ball" of the toes; and then the foot is lifted sheer of the ground with the toes still angulated, so that they clear the ground as the leg swings forwards again. But when the hand is emancipated altogether from the purposes of progression, this action of the extensors disappears. This emancipation takes place in arboreal life, and among the arboreal Primates we see the reduction of the second set of digital extensors in the hand. Most of the monkeys possess the power of bending their fingers backwards at the metacarpo-phalangeal joints as they climb about the branches, but the power becomes

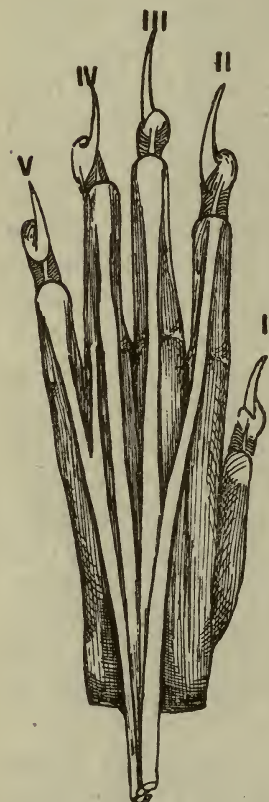

FIG 86.—The superficial extensor tendons of the digits of the manus in the cat.

less in the anthropoids. Most human beings cannot actively extend their fingers far beyond the line of metacarpals; and such as can do it usually regard themselves as being "double-jointed," whatever that may be. In the human hand the digital extensors are merely the correctors of the flexors, for they only straighten the fingers back again after the flexors have bent them, but in the human foot the digital extensors produce an active extension of the digits past the mid-point. Yet even with this limitation of the need of extensors in the hand the whole of the deep tendons do not disappear. The extensor indicis is a well-developed muscle, but the extensor minimi digiti is not uncommonly incorporated almost completely in the common superficial extensor. Why do these two digits retain the double set of tendons? The power of independent extension of the index finger is a thing to which we have previously made reference, and perhaps it may be permitted again to refer to index as the scratching finger and to allude to the old name of auriculates for the little finger. Were Man an animal not of our species, we might assert that double extensors and the powers which they confer are found exclusively in the toilet digits.

FIG. 87.—The deep extensor tendons of the digits of the manus in the cat.

The special extrinsic muscles of the thumb are particularly well developed in Man, for in Man the thumb is characteristically large when comparison is made with other higher mammals. The extensor pollicis longus, inserted into the second phalanx in Man, is present in all the anthropoid apes, but is commonly inserted into both the first and second phalanges, a condition which is also present in mammals of other orders.

The extensor pollicis brevis is usually said to be a muscle which is peculiar to Man, but it would perhaps be more accurate to say that its complete separation from the extensor ossis metacarpi pollicis was a typically human condition. In the Gorilla alone among the anthropoids is there a muscle which nearly answers the description of the characteristic human muscle, for here the extensor brevis is inserted in part into the first phalanx, the rest of the tendon being attached to the metacarpal (Bischoff and Hepburn). In the Gibbon, Chimpanzee, and Orang-utan the whole of what may be considered as a separate slip from the extensor ossis metacarpi pollicis is inserted into the metacarpal of the thumb, but none of it passes to the phalanx. In the monkeys it is not possible even to separate this portion from the typical extensor ossis.

The extensor ossis metacarpi pollicis, unlike the extensor pollicis brevis, is a typical mammalian muscle, but it is inserted rather to the carpus than to the metacarpal of the thumb in the anthropoid apes. In Gibbons and Chimpanzees the muscle is inserted to the carpus, mainly into the trapezium, and sometimes partly into an additional sesamoid. In the Orang a portion of its tendon sometimes joins the base of the metacarpal and in the Gorilla the base of the metacarpal is the main insertion. But in many of the lower Primates the muscle resembles that of Man, and truly deserves its name of extensor ossis metacarpi pollicis, and the same may be said of the muscle in many generalised mammals.

CHAPTER XVIII.

THE INTRINSIC MUSCLES.

THE intrinsic musculature of the hand consists of an intricate and variable system of short muscles, the individual members of which are somewhat difficult to display in the process of routine practical anatomy. It is but rarely that, in all details, complete symmetry is found in the intrinsic muscles of the right and left hands, and, as is but natural, it is extremely common to find those of the right hand far better developed than those of the left. Being small muscles, and crowded together as they are in the limited space of the palm of the hand, the determination of the precise action of some of them is a matter of considerable difficulty, and, as we shall see, some difference of opinion still exists upon this question.

In their anatomical disposition they are arranged into three fairly well-defined groups, one group being assigned to each marginal digit and the third, or central, group being present in connection with the three central digits.

The first and most specialised group, which is associated with the thumb, is known as the thenar musculature, and forms by its prominence the thenar eminence, or "Mount of Venus," which clothes the metacarpal of the thumb. The second group, which is not so well developed nor so bulky, consists of muscles acting on the little finger, and constitutes the hypothenar group, which causes the hypothenar eminence, or "Mount of Mars," upon the postaxial margin of the palm. The central group consists of the muscles which are massed between the metacarpal bones of the centre of the hollow palm and the little muscles arising from the deep flexor tendons, and are known as the interossei and lumbricals.

The thenar group comprises four distinct muscles:—

(1) *The Abductor Pollicis Brevis;* (2) *The Flexor Pollicis Brevis*=flexor secundi internodii pollicis (Douglas) = flexor primi

et secundi ossis pollicis (Cowper); (3) *The Adductor Pollicis*, which is often described as two muscles, (*a*) adductor pollicis transversus and (*b*) adductor pollicis obliquus; (4) *The Opponens Pollicis* = flexor ossis metacarpi pollicis (Innes) = flexor primi internodii pollicis (Douglas).

(1) *The Abductor Pollicis.*—This is the most superficial member of the group, and is characteristically a flat strap-like band of muscle which arises chiefly from the anterior annular ligament with the lower border of which it is continuous at times as far as the pisiform bone. Attachments of the muscle to the carpal bones are of very minor importance, and it is only occasionally that a few fibres arise from the scaphoid or trapezium. Somewhat more commonly an attachment is derived from the tendon of the extensor ossis metacarpi pollicis, or perhaps it would be more accurate to say that a portion of the tendon of the extensor ossis metacarpi pollicis frequently passes to this muscle (see Fig. 88). At the metacarpo-phalangeal joint of the thumb the fleshy fibres converge upon a flattened tendon which is inserted into the tubercle upon the base of the first phalanx upon its radial aspect. As a rule, this tendon gives off a superficial lamella which passes on to the dorsum of the first phalanx to join the tendon of the extensor pollicis longus.

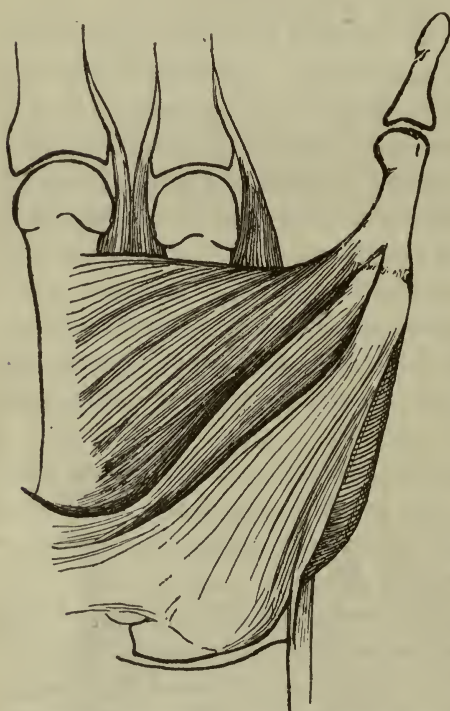

Fig. 88.—The superficial view of the intrinsic muscles of the thumb. The adductor, flexor brevis and abductor are in order from above downwards; the opponens is at the extreme radial margin.

(2) *The Flexor Pollicis Brevis* is a muscle which has received very varying descriptions, for different authorities have defined

the precise limits of the muscle in very different ways. Quite definitely, the whole mass consists of several portions, and it is usually described as being a bicipital muscle, but the two heads of the flexor pollicis brevis, as defined by different authors are obviously not identical throughout the published descriptions. We will define these slips as they are commonly present and discuss their synonyms in order (see Fig. 89).

(A) A superficial or external slip arising from the outer two-

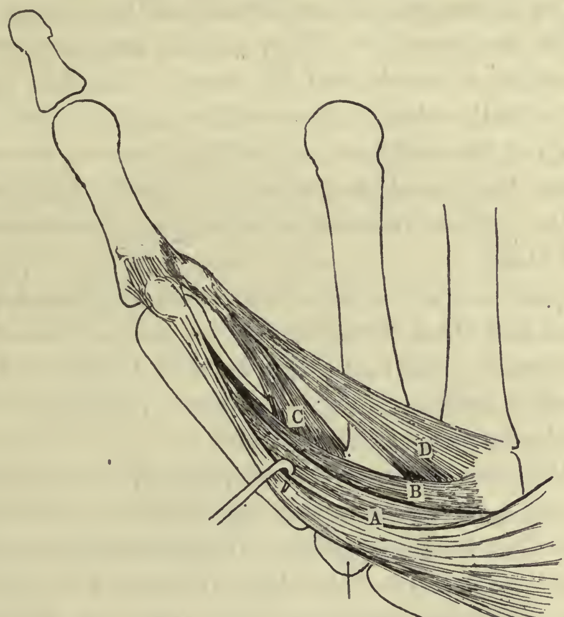

Fig. 89.—Diagram to explain the various elements that have been regarded as constituting the flexor pollicis brevis.

thirds of the annular ligament and from the trapezium. This portion runs along the radial side of the tendon of the flexor pollicis longus, and is inserted into the *radial* sesamoid bone of the metacarpo-phalangeal joint and the base of the first phalanx. This constitutes the superficial or external head of the muscle of most authors, and is the abductor internus of Soemmering and Henle ; by Flemming it is regarded as the only slip which is entitled to the name of flexor brevis.

(B) A deeper portion which arises from the trapezoid and os magnum, which is deep to the tendon of the flexor pollicis

longus and is also inserted into the *radial* sesamoid and the base of the first phalanx. This portion constitutes the deep head of the flexor brevis of Cruveilhier and most French and some few English anatomists. By Henle it is regarded as the superficial or external head of the true flexor brevis, and by most English anatomists and by Flemming it is considered as a part of the adductor pollicis.

(C) A small portion which arises from the ulnar aspect of the base of the metacarpal of the thumb and runs along the ulnar side of the tendon of the flexor pollicis longus to be inserted into the *ulnar* sesamoid and the base of the first phalanx in common with the oblique fibres of the adductor pollicis. This is the deep or internal head of the flexor brevis of most English anatomists, but by other authors is usually regarded as the first of the palmar interosseus series—the interosseus primus volaris of Henle.

(D) A portion which arises from the os magnum and bases of the second and third metacarpal bones and is inserted into the *ulnar* sesamoid. This is the deep head of Albinus and some few more recent authors, but it is now practically universally recognised as a part of the adductor.

From this mass of variant descriptions it is exceedingly difficult to define a muscle which will embrace all of the many definitions that have been given. The difficulty is made greater by the fact that many of the slips are themselves liable to considerable individual variation. We shall see later that the dividing line between a short flexor and an interosseus muscle is by no means sharp, but it may be said at once that there is much reason for urging that the French custom of recognising the slip (*c*), which we term the " deep head," as the true first palmar interosseus, is the logically correct proceeding. There is little fault to be found with naming slip (*a*) as a true flexor brevis muscle. It is distinct enough from the abductor to be regarded as the " superficial head " of the flexor brevis, even if we do not claim it as a complete and separate muscle. Slip (*b*) is distinct from the adductor in being inserted to the radial, and not the ulnar, sesamoid, and this may perhaps be some valid reason for the retention of this portion as the " deep head " of

the true flexor brevis pollicis. Slip (*c*) is far best classed among the palmar interossei, and slip (*d*) is obviously only a portion of the adductor. If, therefore, it is too radical a change for English anatomists to go so far as Flemming in describing only (*a*) as the short flexor of the thumb, it may be a step in the right direction to adopt the retention of (*a*) and (*b*) after the descriptions of the French.

From a practical point of view the greatest difficulty in dealing with these muscles is the fact that when the clinician reports the flexor brevis muscle to be acting it is impossible to be certain exactly what muscular slip he recognises as the flexor brevis, and exactly what movement he expects it to produce. Indeed, it will often be found that the clinician himself has no very precise idea. This confusion arises for the most part in connection with cases of recovering function after repair of nerve injuries; and it would certainly appear to be a better plan in clinical medicine if we recognised the flexor brevis as a muscle which is inserted into the *radial* sesamoid, and which is innervated by the median nerve. There is no doubt whatever that our superficial head (slip (*a*)) falls into this definition, but with slip (*b*) the matter is not so simple, for it is normally supplied by the ulnar nerve. Slip (*c*) is inserted to the ulnar sesamoid, and is innervated by the ulnar nerve, and the same holds true for slip (*d*), so neither of these muscles has any claim to inclusion.

Having cleared the way so far, the description of the remaining slips of the short muscles of the thumb becomes more simple.

(3) *The Adductor Pollicis* consists of two more or less well separated portions which are described as the adductor pollicis transversus and adductor pollicis obliquus. (*e*) The transverse portion arises from the front of the metacarpal bone of medius, its area of origin extending from the base of the bone to within a quarter of an inch of the head. The muscle is fan-shaped, and is inserted by a tendon to the ulnar sesamoid and the base of the first phalanx of the thumb. (*f*) The oblique portion arises from the bases of the metacarpals of index and medius, and from the os magnum, and is inserted into the ulnar sesamoid along with (*e*). This is the slip which we have indicated as (*d*) in describing

the flexor brevis. (*g*) In addition to this is the part alluded to as (*b*) in the previous description, and which arises from the os magnum and the trapezoid and is inserted into the *radial* sesamoid. The whole of this muscle is, as a rule, supplied by the ulnar nerve.

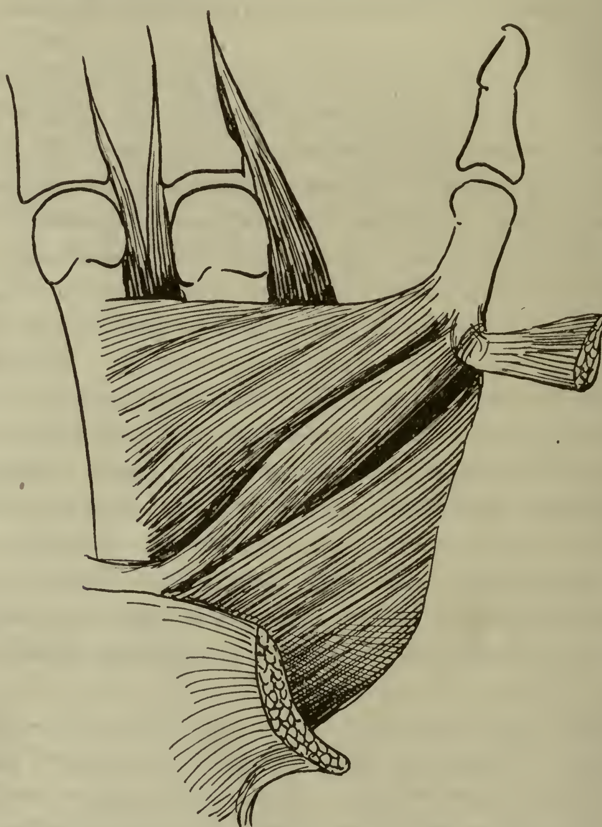

Fig. 90.—The deep layer of thumb muscles. The short abductor is divided and turned aside.

Now it will be noticed that in all this sheet of muscle only one slip presents any very real difficulty, and that is the one (*b*) which English authors class as adductor obliquus pollicis, despite the fact that it is inserted to the radial instead of the ulnar sesamoid bone, and which French authors regard as the deep head of the flexor brevis pollicis, although, unlike the rest of this muscle, it is supplied by the ulnar nerve. It may matter but little what

names are given to the actual slips, but it is essential for understanding the movements of the thumb, and estimating recovery in cases of nerve lesion, to bear in mind the fact that one of the muscles of the thumb, which is supplied by the ulnar nerve, is inserted into the radial sesamoid and radial side of the base of the first phalanx.

(4) The fourth of the special short muscles of the thumb—the *Opponens Pollicis*—is a perfectly distinct and characteristic muscle. It arises from the anterior annular ligament and from the ridge on the trapezium, under cover of the abductor pollicis, and it is inserted into the whole length of the radial ridge on the metacarpal bone of the thumb.

As might be imagined from the intricate nature of these small and crowded muscle masses, the actions of the individual named muscles are by no means easy to determine. The function of the opponens is the most distinct, and its action is the most easy to isolate either by electrical stimulation or by the performance of voluntary movements. The opponens is a rotator of the metacarpal during adduction. When it contracts, it pulls the radial or volar border of the metacarpal towards the ulnar side of the hand, and thus it turns the thumb round as it moves from radial to ulnar side, and brings the pad of the terminal phalanx of the thumb into contact with the palmar surface of the remaining digits. Since it gains its whole insertion into the metacarpal, it produces no action upon the metacarpo-phalangeal joint, and it effects the movement of opposition only as far as rotation and adduction of the metacarpal will produce this. In its action of rotation, of the thumb, it is the opponent of the extensor pollicis longus, which produces the opposite rotation. All the other short muscles of the thumb, by being inserted to one or other of the sesamoids and to the base of the proximal phalanx, are enabled to produce movements on the metacarpo-phalangeal joints. The abductor pollicis is a flexor of the metacarpo-phalangeal joint. It also pulls the thumb straight out from the palm of the hand. This last action needs careful study, since it differs from that abduction produced by the extensor ossis metacarpi pollicis or abductor pollicis longus. The movement produced by the short abductor may be said to be effected upon the

thumb held midway between pronation and supination. In this position the ulnar margin of the thumb is in contact with the palmar aspect of index. Contraction of the short abductor now lifts the thumb away from the index finger and pulls it bodily from the palm of the hand. The opponent to this action of abduction is for the most part the so-called "deep head" of the flexor brevis or first palmar interosseus (part (*c*)). In most voluntary movements the superficial head of the flexor pollicis brevis (part (*a*)) acts with the abductor pollicis brevis, but naturally, from the fact of its more extended ulnar origin, its action as a flexor of the metacarpo-phalangeal joint and a rotator of the thumb is greater. Since these muscles, and especially the abductor brevis, gain a partial insertion into the dorsal expansion of the extensor tendons, it is mechanically possible for them to produce an extension of the terminal phalanx of the thumb. In some cases of paralysis of the long extensor a very feeble movement of extension of the top joint may be effected by these muscles, but this is by no means a constant action.

The adductor mass is, as we have seen, a complex of several slips of muscles. All that portion which is inserted into the ulnar-sided sesamoid (parts (*e*) and (*f*)) acts as a flexor of the metacarpo-phalangeal joint as well as an adductor. In this movement of adduction, the thumb, held midway between pronation and supination, is swept straight across the palm of the hand. This movement of adduction is therefore not an action in opposition to that produced by the short abductor, but rather to that of the extensor ossis metacarpi pollicis and extensor pollicis brevis. Like the other flexors of the metacarpo-phalangeal joint, its action is normally accompanied by an extension of the distal joint, and this action appears to be effected mostly by putting the tendon of the long extensor on the stretch. Lastly, there is the portion of the adductor obliquus, or deep head of the flexor brevis (Cruveilhier, etc.), which we have labelled (*b*), and which is inserted to the radial sesamoid. This muscle, like the opponens, can cause rotation of the thumb, and, like the superficial head of the flexor brevis and abductor, can lift the thumb from the palm and flex the metacarpo-phalangeal joint. For all practical purposes we may therefore

say that opposition is a complex movement; that opponens and abductor, and superficial head of flexor brevis innervated by the median, are the greatest factors in producing the movement; but that the muscle which is innervated by the ulnar, and which is termed by the French the "deep head" of the flexor brevis, can also act in the same way, and further that the slip which we have seen passing from the extensor ossis metacarpi pollicis to the abductor enables a muscle belonging to an altogether different group to share in this complex movement. As for extension of the terminal joint of the thumb by the action of the short muscles, while we may admit that in some cases it may be an actual active movement due to the pull on the dorsal expansion, in far more cases it amounts to little more than a passive extension of the terminal joint brought about by an active flexion of the proximal one.

Fig. 91.—The superficial view of the intrinsic muscles of the little finger, showing the abductor and flexor brevis from ulnar to radial side.

The hypothenar muscles attached to the little finger are in their general disposition not widely dissimilar from those we have already studied in the thumb. Three named muscles are included in the hypothenar group:—

(1) *The Abductor Minimi Digiti* = extensor tertii internodii minimi digiti (Douglas); (2) *the Flexor Brevis Minimi Digiti* = flexor parvus (Innes) = abductor minimi digiti (Cowper and Douglas); and (3) the *Opponens Minimi Digiti* (Albinus and Innes) = flexor primi internodii minimi digiti (Douglas).

As these muscles are at present defined, they may be taken as very fairly representing the homologues of the similarly named muscles of the thumb. (1) *The Abductor Minimi Digiti* is a slender fusiform muscle which arises from the pisiform bone and its ligaments, and through these ligaments it maintains continuity with the tendon of the flexor carpi ulnaris and gains

an attachment to the anterior annular ligament. It is inserted into the base of the first phalanx of the little finger upon the ulnar side, and from this insertion a well-marked slip passes into the dorsal expansion of the long extensor tendon. In this last insertion it resembles the abductor of the thumb, and justifies the name given to it by Douglas.

(2) *The Flexor Brevis Minimi Digiti*, situated nearer to the centre of the palm of the hand, arises from the anterior annular ligament and from the hook-like process on the unciform. The tendon of insertion joins the palmar part of the capsule of the metacarpo-phalangeal joint and the sesamoid bone, which is usually present in that situation. From this sesamoid the tendon runs in common with that of the abductor, and is inserted into the ulnar aspect of the base of the first phalanx.

Fig. 92.—The deep layer of muscles of the little finger. The abductor and short flexor are cut and turned aside to expose the opponens.

(3) *The Opponens Minimi Digiti*, the most bulky of the three muscles, is situated deep to the other two. It arises from the anterior annular ligament, and from the unciform, and is inserted into the whole length of the metacarpal of the little finger, the fibres passing across the front of the bone to its ulnar border.

As the carpo-metacarpal and metacarpo-phalangeal articular surfaces of the little finger are far more simple than those of the thumb, the movements of these parts of the little finger are more easy to isolate than are those with which we have just dealt in connection with the thumb. The abductor certainly merits its name: it abducts the little finger at the metacarpo-phalangeal joint, an action in which it is assisted by the extensor minimi

digiti. It is also able to flex the finger at the metacarpo-phalangeal joint and, by virtue of its dorsal insertion, to extend the two terminal phalanges. The short flexor bends the finger at the metacarpo-phalangeal joint. The opponens does not deserve its name in the same way as does the opponens pollicis, for true opposition of the little finger is an action which does not occur in any animal. It adducts the metacarpal, and pulls it in a palmar direction, thus narrowing the palm of the hand, and increasing the prominence of the hypothenar eminence, thereby deepening the "cup of Diogenes." But the power of rotation, which is so conspicuous in the case of the thumb, is almost entirely lacking in the little finger.

The remaining intrinsic muscles of the hand are known as the interossei and the lumbricals.

The interossei are short muscles which arise from the metacarpal bones and are inserted to the phalanges, and they are arranged in two strata, the one, palmar interossei, being nearer the flexor surface, and the other, dorsal interossei, being nearer the extensor surface, of the hand.

The *Palmar Interossei* are generally said to be three in number, but a good deal of confusion exists in the descriptions which have been given of the individual muscles. Starting from the radial side of the hand, we have first that slip of muscle which arises from the ulnar side of the basal portion of the metacarpal of the thumb, and is inserted into the ulnar-sided sesamoid of the metacarpo-phalangeal joint, and so into the ulnar side of the base of the first phalanx. This is the muscle which, as we have seen, most British anatomists class as the "deep head" of the flexor pollicis brevis, but which is far better regarded as the *first palmar interosseus*. Next is a similar slip of muscle arising from the ulnar side of the metacarpal of index, and inserted into the ulnar side of the first phalanx, as well as into the dorsal expansion of the extensor tendons, in a manner common to all the interossei, and which will be examined in detail later. This is the *second palmar interosseus* = first palmar interosseus of most authors = posterior indicis (Innes) = first interosseus (Douglas). No member of this series is associated with medius. In connection with annularis is a similar muscle which arises on

the radial side of the metacarpal, and is inserted into the radial side of the first phalanx. This is the *third palmar interosseus* =

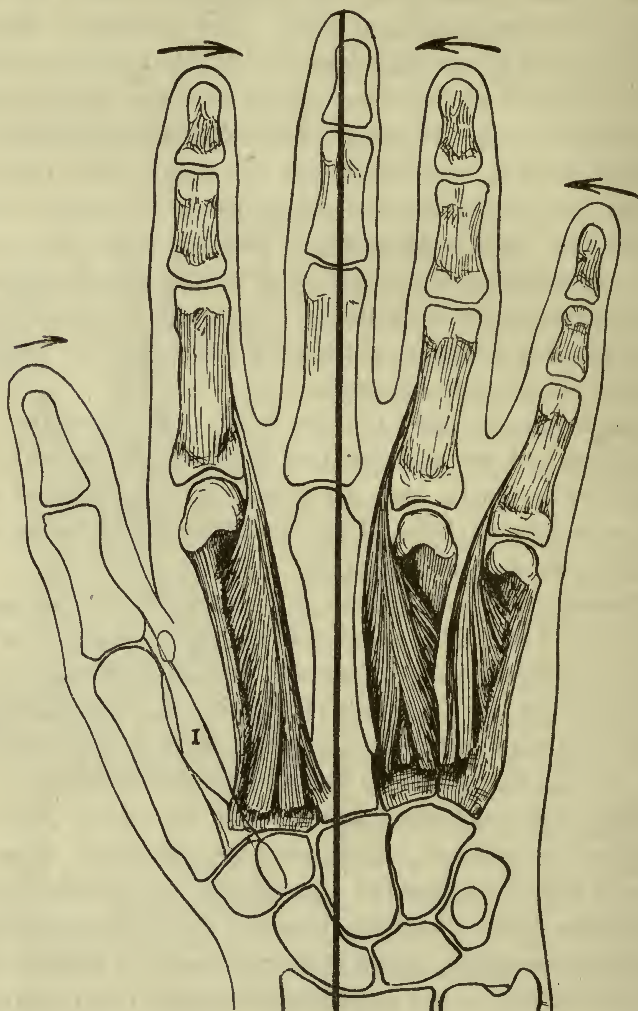

Fig. 93.—The palmar surface of the hand showing the *adducting* interosseous muscles. The first member of the series is indicated only in outline.

second palmar interosseus = prior annularis (Innes) = fourth interosseus (Douglas).

The little finger has a similar muscle on the radial side of its first phalanx; and this is the *fourth palmar interosseus* = third

palmar interosseus = interosseus auricularis (Innes) = sixth interosseus (Douglas).

The *Dorsal Interossei* differ from those described, not only in their position, but also in the fact that they are bicipital muscles, each muscle arising from two adjacent metacarpal bones. Again starting from the radial side of the hand, the first of the series is a large and fleshy muscle which arises from adjacent sides of the metacarpals of the thumb and index finger, and is inserted to the radial side of the first phalanx of the index. This is the modern *first dorsal interosseus* = abductor indicis of Albinus and most of the earlier anatomists, or the semi-interosseus indicis of Winslow. The next in the series arises from the adjacent sides of the metacarpals of index and medius, and is inserted to the radial side of the first phalanx of medius. This is the *second dorsal interosseus* = prior medii of Innes = second interosseus (Douglas). A similar muscle arises from the adjacent sides of the metacarpals of medius and annularis, and is inserted into the ulnar side of the first phalanx of medius. This is the *third dorsal interosseus* = posterior medii of Innes = third interosseus (Douglas). The last member of the series arises from the adjacent sides of the metacarpals of annularis and minimus, and is inserted into the ulnar side of the first phalanx of annularis. This is the *fourth dorsal interosseus* = posterior annularis of Innes = fifth interosseus (Douglas). One other member of this series still remains for description. This muscle arises from the flexor surface of the base of the metacarpal of index, from the tendon of the flexor carpi radialis, and the ligaments connected with the palmar surface of the trapezoid; it is inserted to the sesamoid on the radial side of the metacarpo-phalangeal joint of index, and to the radial side of the base of the first phalanx. This is the prior indicis of Innes, or extensor tertii internodii indicis of Douglas, or, as we shall see when we discuss the morphology of these muscles, it is perhaps better termed *flexor brevis indicis.* In most recent works on human anatomy this muscle receives neither name nor notice.

All the muscles of the interosseus series are ultimately inserted to the digits in the same manner. The tendon of insertion frees itself of muscular fibres at the level of the meta-

carpo-phalangeal joint. It gains an insertion to the proximal phalanx at the lateral tubercle on the side to which the particular

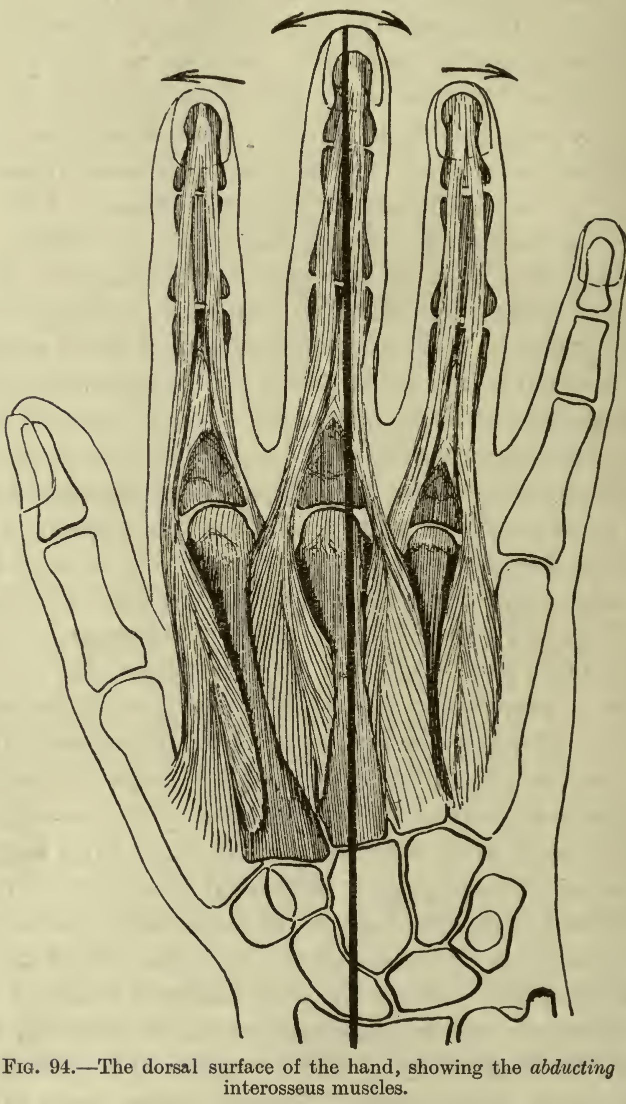

Fig. 94.—The dorsal surface of the hand, showing the *abducting* interosseus muscles.

interosseus tendon runs. This is, however, only a part of its insertion, for the tendon runs over the sides of the phalanx to expand upon its dorsum into the broad lateral portions of the extensor aponeurosis. The tendons of opposite sides interlace

across the middle line on the dorsum of the proximal phalanx, and they are for the most part inserted into the base of the medial

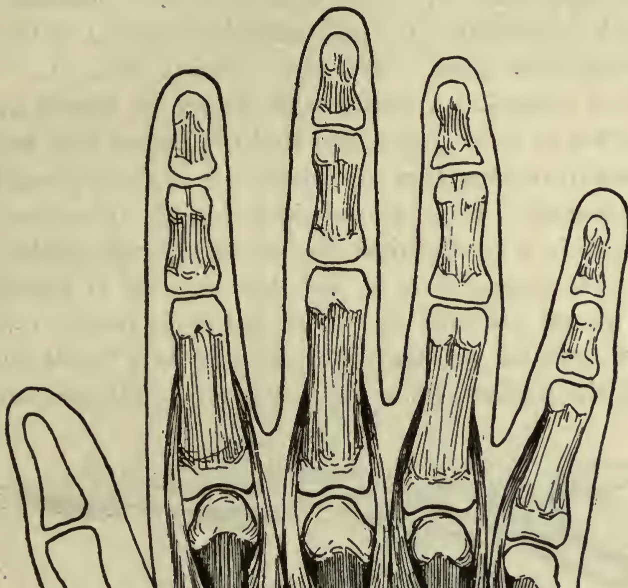

FIG. 95.—The palmar surface of the hand showing the whole series of interosseus muscles. X indicates the M. flexor brevis indicis.

phalanx. The lateral portions of the extensor aponeurosis, reinforced in the case of the radial-sided tendons by the insertion of the lumbricals, join the periosteum on the dorsum of the terminal phalanges.

One action of the interossei is at once apparent, for, since each little muscle is confined to one side of the digit and is inserted unilaterally upon the base of its first phalanx, it will tend by its contraction to cause lateral movement in the meta-carpo-phalangeal joint. We have already seen that in the position of extension a considerable degree of lateral mobility is permitted in these joints, and that the fingers may be spread apart and drawn together by movements of the phalanges upon the metacarpus. It is also obvious that the interosseus series is arranged in a symmetrical way about the axis of the middle finger. The arrangement is such that one set of muscles (the palmar group) will pull the thumb and index finger in an ulnar direction, and the annularis and minimus in a radial direction, towards the medius, while the dorsal group will pull annularis

Fig. 96.—Side view of a digit to show the extensor tendon (E) and the attachment of the interosseus (I) and lumbrical (L).

in an ulnar direction and index in a radial direction away from medius, and will move medius itself towards the radial and ulnar sides. The palmar group is therefore commonly known as the adducting interossei, and the dorsal group as the abducting interossei. We have already seen that adduction and abduction of the digits may be brought about by the action of the extrinsic flexors and extensors, and at times this action is mistaken for real interosseus movement in cases of nerve injury resulting in paralysis of the interossei. But though the extrinsic extensors may spread the fingers as a fan is opened, and the long flexors close them together again, no muscle group save the interossei can move the middle finger from side to side in the plane of the extended hand.

The other actions of the interossei are produced by their curious course from the palmar surface of the hand to the dorsal surface of the digits. The muscles and their tendons are situated

upon the palmar aspect of the metacarpo-phalangeal joints, and their action is to flex the joints. But beyond the metacarpo-phalangeal joints the tendons become dorsal, and their action is to depress the proximal interphalangeal joint and so to extend the middle phalanx at this joint, the terminal phalanx

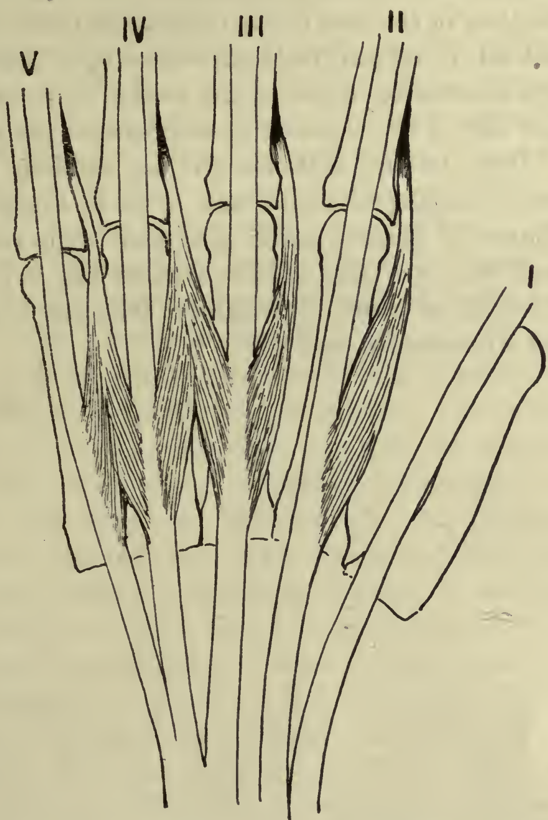

Fig. 97.—The tendons of the deep digital flexor and the lumbrical muscles.

being extended at the same time. The flexor brevis indicis is probably a simple flexor of the metacarpo-phalangeal joint of the index finger.

The remaining intrinsic muscles of the hand are the curious little lumbricals attached to the tendons of the flexor digitorum profundus. These are slender worm-like little muscles numbered from one to four from the radial to the ulnar margin of the hand.

They arise from the palmar and radial sides of the tendons of the flexor profundus. The first arises, as a rule, from the radial side of the tendon for index, the second from the radial side of the tendon for medius, the third from the adjacent sides of the tendons for medius and annularis, and the fourth from the adjacent sides of the tendons for annularis and minimus. Each arises at the level of the base of the metacarpal bone, and passes to the radial side of its own metacarpo-phalangeal joint. From here it passes as a tendon, distal to the tendon of the interosseus, to the radial side of the extensor aponeurosis on the dorsum of the digit. These strange little muscles are certainly flexors of the metacarpo-phalangeal joints, and to them Cowper rightly gave the name of flexores primi internodii digitorum. It is possible that they are also able to extend the two terminal phalanges, but there is but little clinical evidence to make this action at all a convincing one.

CHAPTER XIX.

The Morphology of the Intrinsic Muscles.

There are few problems in comparative myology which present more difficulty, or upon which more diverse opinions are held, than that of the question of the primitive type, and the derivation of the intrinsic muscles of manus and pes. Bardeleben, Bischoff, St. John Brooks, Cunningham, Dobson, Flemming, Hepburn, Humphrey, Ruge, Testut, Turner, Wood, and Young are a few only of the army of anatomists who have written special treatises devoted entirely to some aspect of this question. Yet, despite the accumulated researches of all these workers, it is difficult to give the student a concise account of the morphology of the intrinsic muscles of the hand which could be considered as one reached by anything like a general agreement. Followed either by the route of phylogeny or of ontogeny, numerous difficulties are presented to the investigator who attempts to unravel the story of these little muscles. In probing any problem of myology relating to no matter what portion of the human body, we cannot proceed far without facing the all-important question as to which condition is truly to be considered as primitive, and which the derivative. In the study of the hand this difficulty is of more than ordinary magnitude. We have seen that in very many features the human hand is astonishingly primitive in its anatomical structure, but we all know that Man is regarded as a high type of the mammalia. Are we therefore to derive the condition of the intrinsic muscles of his hand from that seen in typical lower mammals, or are we to take an attitude so unorthodox as to see an elaboration from primitive to specialised in passing from Man to the monkey? Following either alternative along phylogenetic routes will land us into difficulties; and it will be best to deal with these muscles purely from a functional point of view, disregarding altogether Man's place in the scale of nature.

If we consider the physiological needs for movement in the separate parts of the hand and foot, and then note the relative need for the performance of these different movements displayed in different animals, we shall find that there is no great difficulty in accounting for the actual condition of the muscles as we find them in any particular animal. First, the power of flexion and extension will be wanted in each digital joint; secondly, there will be a need to spread the digits apart and to bring them together again; thirdly, there may be more demands made upon the two marginal digits, and they may require a more highly-specialised musculature than the central members. Extension of all the digital joints is made possible by the two long extensors, and the dorsal expansion into which these tendons are inserted. Flexion of the two terminal joints is effected by the two extrinsic flexors. We have already seen that the palmaris longus in its fully functional state acted as a flexor for the metacarpo-phalangeal joints, but this muscle is in a condition of atrophy. We are therefore left with a still unsatisfied need for flexing the metacarpo-phalangeal joints of all the digits and for pulling the digits apart and closing them together again. These functions are discharged by the intrinsic muscles.

Naturally, in some animals more demands will be made upon this group of muscles as short flexors than as adductors or abductors, for the skeletal changes in hand and foot may render the spreading of the digits a very restricted movement. In general we may say that the possibility of spreading of the digits is great in many non-mammalian Vertebrates, in some of the lowest mammals, and in Man, especially, among the Primates. But in most animals which are spoken of vaguely as typical mammals there is but little lateral play permitted in the digits, since they are ranged side by side with their metacarpal bones, closely approximated. In such a case the whole group of muscles will be situated in the palm and sole, there being no room for them between the metacarpal bones, and all the central members of the group may be regarded as short flexors. The short flexors gain their main insertion to the sesamoid bones on the volar surface of the metacarpo-phalangeal joints, and send a small tendon to the dorsum of the digit to join the extensor tendon.

In all the common digitigrade mammals the "interossei" are "flexores breves," and this is sometimes regarded as their primitive condition (Mivart). In some non-mammalian Vertebrates, however, this group of muscles consists of fibres which run almost transversely across the widely splayed metacarpals, and they are so arranged as to effect lateral movements of the digits in either direction, but they do not act as flexors. In such a condition the "interossei" are purely adductors and abductors of the digits, and this is the primitive condition as pictured by some (Humphry). We might say in passing that it is quite unlikely that any very primitive conditions are to be met with in the feet of the digitigrade mammals, since the position of their digits has undergone such great changes from a state which is well known to be primitive.

Fig. 98.—Manus of a dog to show the position of the metacarpal bones and digits.

But in many mammals these muscles are required to act as short flexors as well as lateral deviators of the digits, and then the group becomes differentiated and specialised. Cunningham* and Young, from a study of the palmar and plantar muscles of the Marsupials, came to the conclusion that in the ideal condition the whole group became split into three layers of muscles: (1) a dorsal layer of *abductores,* (2) an intermediate layer of *flexores breves*, and (3) a palmar layer of *adductores*. According to Primrose's interpretation of this plan, the dorsal layer in Man consists of the abductor pollicis, the abductor minimi digiti, and the four dorsal interossei, the intermediate layer of the flexor brevis pollicis, flexor brevis minimi digiti, opponens, and palmar interossei; while the volar layer contains the adductor pollicis alone.

Concerning the dorsal layer there is but little to be said, for

* Intrinsic muscles of the hand in Marsupials (*Journ. Anat. and Phys.*, Vol. XII., 1878. p. 434).

the abducting muscles form a very uniform series. But the intermediate layer is not so simple, for part of its members are occupied with the function of drawing the fingers together, and part with producing flexion of the metacarpo-phalangeal joints. Evidently in Man the differentiation of these muscles is in such a stage that certain fibres are devoted to the double *rôle* of causing approximation of the fingers and producing flexion, but special muscles are developed for flexion only in the case of certain digits. In other words, the palmar interossei are adductors and flexors of the metacarpo-phalangeal joints, but certain digits need more highly developed flexores breves. When the interossei are present as flexores breves in the digitigrade mammals, we have seen that they obtain their flexing insertion at the

Fig. 99.—Diagram of the primitive arrangement of the short digital muscles according to Cunningham. A. Dorsal layer of abductors. B. Intermediate layer of short flexors. C. Palmar layer of adductors.

sesamoids, and in Man also the specialised flexores breves are attached to the sesamoids of the thumb and little finger; but we have also seen that a sesamoid is very frequent in connection with the index, and that a muscle is also developed with sufficient constancy to deserve the name of flexor brevis indicis. When we ask why should these three digits have short flexors as well as adducting interossei, we probably find the answer in the examination of the extensors, for it will be remembered that it is to these digits alone that tendons of the extensor profundus vel brevis digitorum are attached. The special adductor of the preaxial digit (pollex and hallux) is a preaxial muscle which is an ancient possession, and which is only divided into its two portions (obliquus and transversus) by the growth in length of the metacarpals and metatarsals.

It remains now to compare the intrinsic muscles of the hand and foot, and to see in what directions Man differs from those animals placed nearest to him by systematic zoologists.

The abductor, adductor, and flexor brevis of the thumb find

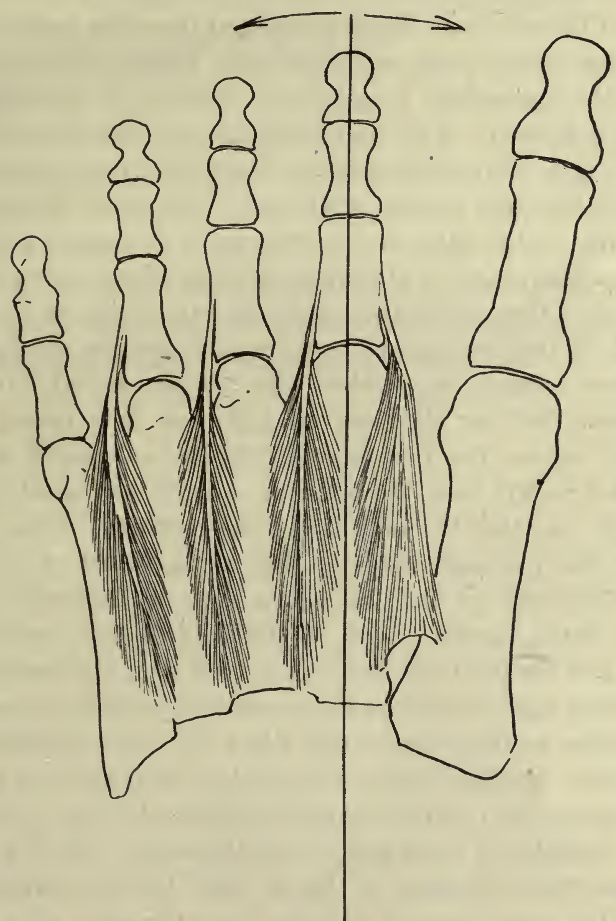

Fig. 100.—Diagram to show the arrangement of the abducting interossei in the foot.

their parallels in similar muscles of the big toe ; but the opponens of the big toe is only an occasional muscle. The abductor and flexor brevis of the little finger are matched by similar muscles in the little toe, but again the opponens of the little toe is only occasionally present as a separate muscle. In every case the

muscle of the foot compares but ill with its representative in the hand, and the movement which it produces in the toes is, of course, extremely unimportant in the average foot of civilised peoples. By far the most interesting contrast in the myology of hand and foot is displayed in the interossei. In the foot the whole of this group is situated more to the volar surface of the metatarsal bones, and, as everybody knows, the movements which the individual muscles are capable of producing are extremely limited. Yet, unimportant as the muscles themselves may be in modern boot-wearing Man, they nevertheless show a most interesting human distinction. We have seen that the symmetry of the interossei of the hand is ranged round the medius or third digit. To this finger the other fingers are adducted, and from it they are drawn apart, and the study of the digital formula of the hand leads us to expect such an arrangement. But great changes have taken place in the digital formula of the human foot, for the preaxial digits are, so to speak, hypertrophied, whilst the postaxial digits are undergoing atrophy. Regarded merely from the point of view of the digital formula, we might say that the mid-line of the human foot had shifted towards the preaxial margin. The arrangement of the interossei shows this, in fact, to be the case, for, instead of these muscles being ranged round the third digit as a centre, they adduct and abduct the other toes to and from the second digit. The second digit in the foot has become the middle line member, and remains as the point of rest when the toes are spread apart and drawn together. In all the monkeys and apes, as we have seen already, the third toe remains primitively long, so that the digital formula for hand and foot is the same. In all monkeys and apes the interossei of hands and feet are arranged in exactly the same manner, all being upon the same plan as that seen in the human hand. Only in the Gorilla does the human type of pedal interossei occur as an occasional variation, and the Gorilla foot is pre-eminent among anthropoid feet in its pseudo-human form and function.

One muscle, the flexor accessorius of the human foot, finds no counterpart in the myology of the hand. It is a muscle of some interest, for though it is well represented in non-mammalian

Vertebrates and primitive mammals, it is generally absent in the anthropoid apes. Bischoff failed to find it in any anthropoid; but occasionally it is present, and a feeble muscle has been noted by Langer, Fick, and Chapman in the Orang-utan; by Hepburn, Gratiolet, and Alix in the Chimpanzee; and by Hepburn and Macalister in the Gorilla.

As for the lumbricals, they too are flexors of the metacarpo-phalangeal joints, and their morphology is extremely uncertain. By Humphry they are regarded as being the equivalents on the second, third, and fourth digits of the flexores breves on the first and fifth. But in many animals they coexist with a full set of flexores breves. Undoubtedly they are an ancient possession, and one which Man shares with his nearest neighbours. Their use as flexors of the metacarpo-phalangeal joints is well seen in cases in which the ulnar nerve is paralysed.

CHAPTER XX.

The Tendons and Tendon Sheaths.

The tendons, or "leaders," are the fibrous and non-contractile tissues developed in connection with the contractile muscles wherever function demands some other quality than that elastic and contractile character which is typical of muscle substance.

Tendons are not merely developed as inelastic bonds which unite muscles to bones, or, in more popular language, all tendons are not "leaders." Tendons are developed wherever a muscle in changing the direction of its action takes a turn round some pulley. Instances of this are seen in the omo-hyoid, the digastric, the superior oblique muscle of the eye, and in the tensor palati among others. They are also present upon adjacent surfaces of muscles wherever much gliding of muscle upon muscle takes place. This condition is well seen in the case of the vastus externus and of the soleus. As an extension of this one may say that tendons are developed wherever the "packing" of structures demands their presence. The biceps, for instance, remains tendinous until it is relieved of the pressure of the overlying pectoral muscles. Tendinous portions are also present in muscles which are compounded of multiple morphological elements. Thus tendinous intersections occur in muscles which are made up of several segmental parts, as the rectus abdominis, the sterno-hyoid, etc. Again, tendons, representing as they do a lower stage of organisation than the higher specialised muscular substance, may be developed merely as a degeneration product of muscles which are waning in importance. We may say that muscle, tendon, and fascia represent definite stages of degeneration. A muscle that is losing its functional importance by entering upon phylogenetic senility tends to become more and more tendinous, and the tendon to become more and more fascial as functional decrepitude overtakes it. The palmaris longus is tending to become less fleshy, and to have a greater

proportion of tendon to contractile muscle substance in its composition. Its tendon is itself becoming more and more fascial as it passes from full functional utility to the category of a mere ancestral remnant. Unless some mechanical reason demands the arrangement, we may generally regard muscles which have a particularly large proportion of tendon in their composition as muscles which are passing into phylogenetic senility. It is for this reason that muscles which have a preponderance of tendon are, as a rule, more difficult to restore to their full function after an injury than muscles which are largely composed of fleshy and contractile fibres.

Tendons of insertion are familiar to every one, since so many of them, and especially those about the wrist and hand, are conspicuous as the familiar leaders which stand out when active movements are performed. But tendons of insertion serve more purposes than that of affording a firm union between muscle and bone. In the case of the deltoid, the very beautiful arrangement of the multiple tendons is obviously a mechanical device for increasing the power of this very complex muscle. Again, "central" tendons, which are so widely represented in the body, are nature's means of achieving the action of a very large number of short fibres, instead of tolerating the less efficient arrangement of a comparatively few elongated fibres performing the work. A tendon must not always be regarded solely as an alternative to a fleshy or fibrous insertion. When a muscle needs to be a powerful one, and one of large bulk, it may be necessary for it to arise from a large number of bony points; but at the same time its action may only be exerted upon one comparatively small portion of the skeleton. In that case it is inserted by a tendon, and this tendon then serves to concentrate the action of the whole contractile mass upon this one definite point. A tendon may, so to speak, "focus" the action of a wide-spread muscle sheet. In the arm we might instance the triceps, which, arising over a wide area, is concentrated in its action upon the olecranon by the development of a discrete tendon. On the other hand, a muscle which arises from a limited and confined area may need to exert its influence over a wide series of bony points. In this case the functional result

is achieved by the muscle giving rise to multiple tendons. The extensor communis digitorum, for example, arises as a simple fleshy mass from the radial condyle of the humerus, but it is required to act upon four digits. It is enabled to perform its action upon these four separate elements by being inserted by means of four tendons. Tendons may therefore be developed either to concentrate or to dissipate the action of a contracting muscle.

When a fusiform limb muscle contracts, its two ends are approximated by a shortening of its total length. In this way a contracting muscle, attached at its two extremities, will pull the two bony points to which it is attached nearer together. Thus when the quadratus femoris acts its fibres shorten, and it pulls the femur straight to the tuberosity of the ischium. But the action of most limb muscles is not so simple as this since for the most part they effect the approximation of bony points by angulating the limb at joints. Now, when a muscle simply effects approximation of bony points without the production of angulation it is commonly in the anatomical condition of a simple fleshy mass, devoid of tendon save for a meagre bond which unites it immediately to bone. But when a muscle by its action causes angulation of parts, and a kinking of its own axis, then, as a rule, tendon will enter largely into its composition, since tendon will transmit the pull of the contracting muscle across any kink. It need not even be the case that the muscle itself produces the angulation by its action; it is enough that it has to act across parts which are habitually angulated for this to be a guarantee that tendon will replace muscle substance where the bending occurs. It is but natural, therefore, that in parts where joints occur at very short intervals, as they do in the hand, the long muscles passing to the part will be almost entirely represented by tendons. The leaders on the back and front of the wrist and hand are therefore expressions, not only of the need to dissipate muscular effort upon the several digits, but of the fact that muscles are acting upon parts which, owing to the numerous joints, are constantly bending. In this process of bending there are degrees which must be noted. Joints have been classified time and again, and to the different classes names

of Greek origin have been given. It is not a matter of great difficulty to learn these names and to remember which joints belong to each named class; but it is to be doubted if the mastery of any of these schemes has armed the student with any very real knowledge of joints. The student would be well advised not to rely too much upon the use of these class names for joints, since he may fancy that when he can assign the correct class name to the joint he necessarily understands the movement of the joint. He would also be wise to avoid the slavish use of names which indicate the direction of movement, since unending confusion may be caused by this misguided attempt at precision. "Flexion" and "extension" are simple terms and readily understood, but when they are applied to the ankle joint, the shoulder joint, and the wrist, they may be productive of great confusion. It is far better to use a few more words and say exactly what a part does than to employ a traditional term and leave the matter open to some doubt. A simple note which says, "The patient is unable to raise the foot," is far more valuable than the apparently more scientific "The power of flexing the ankle is lost." Since flexing the wrist is generally understood to be the act of bringing the palm downwards, it is not at all unnatural that some people might interpret such a note as meaning that the patient could not move the sole of the foot downwards, and such an interpretation might or might not, for all the reader knows, have been in the mind of the person making the note. Confining our attention to the hand, the wrist may be bent from an intermediate position in two directions: the hand may be bent towards the palm (flexion) or bent towards the knuckles (extension). Of these two movements that of palmar bending is the most free and is carried further. But in the case of the fingers they can be bent towards the palmar surface at three joints, the metacarpo-phalangeal joint and the two interphalangeal joints, but they cannot in most people be bent in the direction of the nails, for all that we can do in the way of extension is to straighten them back again. The tendons of the flexors and the tendons of the extensors are therefore situated very differently in the fingers, for, whereas the extensor tendons will merely need to be held

steady as they ride across the prominence of the knuckles, the flexors will have to be bound down to the joints from which they will tend to part company as the muscle contracts. At the wrist, however, both flexors and extensors are subject to the same conditions, since both are capable of producing angulation, and both will need some mechanism for binding them into the concavity which they create by their action. No better illustration of this fact can be given than that which was furnished by the artist Jan Stephen Van Calcar, who provided the drawings for the great work of Vesalius (see Fig. 101). In this little figure are summed up the true functions of those structures which are known as annular ligaments. An annular ligament is a fascial sling which is developed wherever a tendon needs to be bound into place over a joint which is capable of being bent at an angle. We should therefore expect an annular ligament to be developed over the tendons which extend the hand at the wrist joint, as well as over the tendons which flex the wrist. But although the flexors of the fingers will need some retaining ligament at each joint over which they pass, we should not look to see a similar series of ligaments developed in connection with the tendons of the extensors of the fingers, since these tendons produce no angulation of the joints. The binding down of tendons by retention ligaments entails another condition which is of the greatest practical importance. Wherever a tendon is retained by a fibrous sling under which it glides, it will have developed around it a special sheath to facilitate the gliding. This is the synovial sheath of the tendon. Each tendon will run in a tunnel which is surrounded by a fine glistening membrane, known as the synovial membrane, which secretes a fluid known as synovial fluid for the lubrication of the tendon

Fig. 101.—Vesalius's figure explaining the action of annular ligaments. (From "De humani corporis fabrica," Lib. 11, Fig. 167.)

and the tunnel. We may therefore say that, as a general rule, tendons will have synovial sheaths wherever they pass over joints which can be bent at an angle, but that tendons which can

FIG. 102.—The synovial sheaths of the extensor tendons and the posterior annular ligament.

merely straighten parts back from a bent position, and which produce no angulation, will not show the presence of these sheaths. In the hand we should therefore look to find sheaths for the flexor and extensor tendons at the wrist, and sheaths for

the flexor tendons of the fingers, but we should not expect sheaths for the extensors on the back of the hand and on the back of the fingers.

The retaining ligaments for the flexor and extensor tendons are known respectively as the anterior and posterior annular ligaments, and they are, as we have noted previously, specialised portions of that all-pervading fibrous tissue known as deep fascia. These two ligaments passing from the lower ends of the radius and ulna form nature's wrist bandage, to which people doing hard manual labour at times add increased support by means of a leather wrist strap.

The posterior annular ligament is a thickened fascial strap across the lower ends of the radius and ulna, and it holds in place, in a series of tunnels, the extensor tendons which pass over the wrist joint. The extensor carpi ulnaris passing over the ulna has its own tunnel and synovial sheath. The extensor proprius minimi digiti passing over the inferior radio-ulnar joint occupies a separate tunnel, and has its own synovial sheath, which extends as far as the upper third of the metacarpal of minimus. The tendons of the extensor digitorum communis and the extensor indicis proprius passing over the radius occupy a common compartment, and share a common synovial sheath. The extensor pollicis longus which arises on the ulna and passes in a regular pulley groove across the radius to reach the thumb has its own tunnel and its own synovial sheath. The extensores carpi radiales longus and brevis share a tunnel, a groove on the radius, and a common synovial sheath, and so do the tendons of the extensor pollicis brevis and extensor ossis metacarpi pollicis. Each of the extensor tunnels is made up partly by a depression in the bone and partly by the thickened fascia, the bony groove being most developed in the case of the extensor pollicis longus. The synovial sheaths of the extensor tendons are not extensive, and they end above only just beyond the upper limit of the posterior annular ligament, and below extend, as a general rule, only to the basis of the metacarpal bones. The sheath of the extensor proprius minimi digiti is commonly carried the farthest on to the back of the hand.

The anterior annular ligament bridges across the hollow of

the front of the wrist joint, being attached to the prominences of the trapezium and scaphoid on the radial side, and to the unciform and pisiform on the ulnar side. It forms a roof, composed of a specialised portion of the deep fascia, for a carpal tunnel made by the transverse arch of the carpus ; and through this tunnel the flexor tendons pass. In the tunnel are two synovial compartments, the one for the four tendons of flexor digitorum sublimis and the two differentiated portions of flexor digitorum profundus, and the other being a special sheath for the tendon of the flexor pollicis longus. The tendon of the flexor carpi radialis not only has its own synovial sheath, but it has a separate fibrous tunnel upon a deeper plane ; while the tendon of the flexor carpi ulnaris inserted to the pisiform has no tunnel and no synovial sheath. The synovial sheaths for the flexor tendons are far more extensive than those for the extensor tendons under the posterior annular ligament. Above the upper border of the anterior annular ligament the closed synovial space extends as far up as the upper bracelet crease line on the lower part of the forearm, whilst below the lower border it spreads out in the palm as an extensive synovial sac which is generally known as the *palmar bursa.* This bursa extends into the hand as far as the middle of the palm. In the case of index, medius, and annularis the immobility of the metacarpal bone prohibits any further possibility of displacement of the tendon until the metacarpo-phalangeal joint is reached, and therefore the synovial bursa for these tendons ends altogether at the upper border of the superficial transverse palmar ligament, or, as it is often stated in surgical anatomy, at the line of the outstretched thumb. But in the case of the thumb and little finger the mobile metacarpal renders the palmar play of the tendons far more free, and the synovial sheath accompanies the tendons of these two digits beneath the transverse ligament without any interruption. The flexor tendons do not lie absolutely free within the palmar bursa, but are attached to the wall of the bursa by an extremely fine fold of synovial membrane. In this arrangement is seen an almost exact parallel to the suspension of the intestines to the abdominal wall by the mesentery. In both cases the functional end attained is the same, for the maximum

of mobility is permitted to the structure within the serous space, and at the same time a bond is maintained along which the blood-

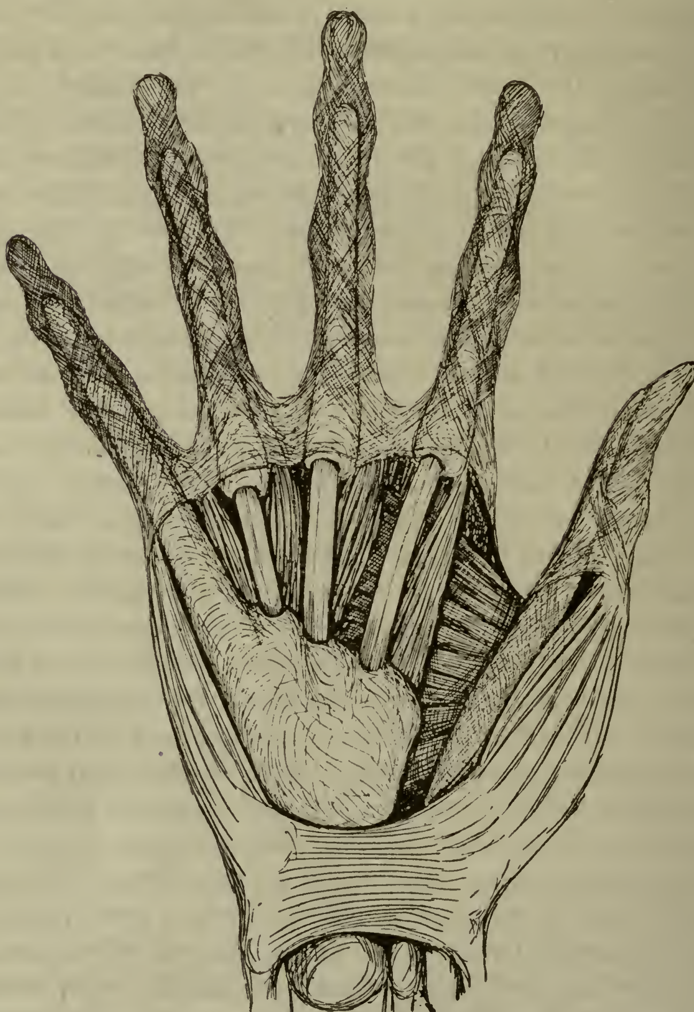

Fig. 103.—The palmar bursa and the sheaths of the flexor tendons. The anterior annular ligament is left in position.

vessels may reach the freely mobile structure. The " mesenteries " of the superficial and deep flexors of the fingers are attached to the radial wall of the palmar bursa, while the tendon of the flexor pollicis longus is attached by a " mesentery " to

the ulnar wall of its own serous tunnel. Although for index, medius, and annularis the serous sheath comes to an end at the upper border of the transverse ligament, it is necessary that they should start again as the tendons pass into the fingers. It is obvious that the flexor tendons must be bound down to the flexor surface of the three joints over which they pass, and this binding down is effected by the development of a very beautiful fibrous tunnel which carries the tendons over the metacarpo-phalangeal and the two interphalangeal joints. This tunnel is known as the *thecal sheath*, or *theca*, and like the palmar bursa itself, it is lined by delicate synovial membrane and lubricated with fluid. In each thecal sheath, except that of the thumb, there are two

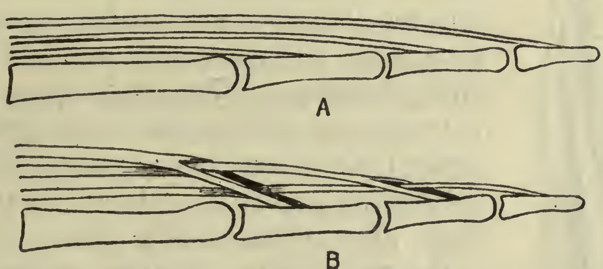

Fig. 104.—Diagram to show the arrangement of the flexor tendons in relation to the joints. B represents the actual condition in the animal body.

tendons of the deep and superficial flexors. In the case of the thumb the single tendon of the flexor pollicis longus alone occupies the whole sheath from forearm to the base of the terminal phalanx.

Within the thecal sheaths of the fingers the tendons are again suspended upon partial "mesenteries" which pass from the deep wall of the sheath to the back of the tendon. These partial mesenteries are known as the *vincula tendinum*. They are somewhat variable in their disposition, but usually a short bond near the insertion and a longer bond further back unite both the deep and the superficial tendons to the thecal sheath and carry vessels to the tendons.

Now, apart altogether from the binding down of the flexor tendons by the thecal sheath, it is to be noted that the arrangement of the tendons themselves tends towards this functional

end. The flexor sublimis itself acts as a sling for the flexor profundus, and doubtless the very beautiful arrangement of these two tendons favours their proper retention during action.

Fig. 105.—The arrangement of the flexor tendons of a finger. The synovial sheath is removed.

It might seem at first sight that with three serial joints to be moved (metacarpo-phalangeal, proximal, and distal interphalangeal) and three muscles to move them (the obsolete palmaris longus, flexor sublimis, and flexor profundus), the simplest plan would be for the most superficial muscle to act upon the distal joint and the deepest on the most proximal joint. But in the animal body an exactly opposite plan prevails, for the deepest muscle acts upon the distal joint, and the most superficial upon the most proximal joint. The great advantage of this arrangement appears to be that, as each tendon is inserted to its proper bone, it may form a retention bond for the tendon passing over to the next distal bone. (See in diagram, Fig. 104.)

The very striking behaviour of the perforated and perforating tendons has excited the admiration of all anatomists, and several explanations have been given to account for the fact. No one can accuse William Cheselden (1688—1752), the great surgeon of St. Thomas's, of having been an imaginative anatomist, but his fancy was much taken by, and his speculation was greatly exercised upon, the arrangement of these tendons. It was from him that the Rev. William Paley took the description of a mechanism which excited his admiration, and of which he said: "There is nothing, I believe, in a silk or cotton mill, in the belts, or straps, or ropes, by which motion is communicated from one part of the machine to another, that is more artificial, or more evidently so, than this perforation." Here it is only the word "artificial" which may ring untrue upon the more modern ear.

From a practical point of view the thecal sheaths are of the utmost importance, since they form tunnels which, once infected, provide free passage for the tracking of inflammatory processes. Since the flexor profundus tendon is inserted to the base of the distal phalanx, the thecal sheath comes to an end here upon all the digits, and therefore an inflammatory process of the terminal pulp of the finger does not invade the sheath if it does not extend towards the distal interphalangeal joint. The arrangement of the palmar bursa is subject to some variations, but as a rule it is in free communication with the thecal sheath of the little finger, and an inflammatory process of this finger extending down to the base of the terminal phalanx is therefore capable of producing far more extensive mischief than a similar condition in index, medius, or annularis. It occasionally happens that the flexors of the index, like the flexors of the thumb, have a synovial sheath of their own in the palm of the hand, and this perhaps is another tribute to the distinction of the human index finger. When inflammatory products invade these sheaths and track along them, it is necessary to make free incisions into the sheaths to permit of their thorough drainage. It is easy to take a knife and make "free and early incisions in the middle line of the finger," but two cautions are necessary. We have already noted the disability which may be inflicted by the development of scar lines which run at right angles to normal flexure lines, but this is a trivial disability compared with that inflicted by severing the bonds which normally hold the flexor tendons down in their passage over joints. Any surgeon who would be tempted to slit up the whole length of a flexor tendon sheath should first study the woodcut in the "Fabrica" of Vesalius, published in the year 1543.

FIG. 106.—The arrangement of the extensor tendons upon the back of a finger. There is no synovial sheath.

CHAPTER XXI.

The Hand and the Brain.

Hitherto, in following a few of the lessons in general anatomy that may be learned from a study of the human hand, we cannot fail to have been struck with the fact that when we look for remarkable specialisations, for anatomical perfections, or wonderful human adaptations as distinguishing our hands from the hands of monkeys and anthropoid apes, our search is rather a vain one. Indeed, it becomes apparent that, in many respects, our hands are constructed upon a plan which is more primitive, more like what we may picture as that characteristic of the earliest mammals, than are the hands of those Primates placed nearest to us in zoological classification. There is no need to go further afield, and to point out how very much more primitive and unspecialised are our hands when comparison is made with such lower mammals as cats, dogs, or horses. Now this conclusion at which we have arrived appears to be altogether at variance with what we know of the wonders of the human hand as a functional organ. It would seem absurd to regard Man's hand as nearer the primitive type from which such an apparently inferior structure as the fore paw of the dog has been derived by specialisation, and certainly it appears difficult to reconcile such an anatomical finding with the numerous eulogies of the human hand that have been penned by human anatomists. Now, many of these eulogies are written rather unfairly, for in drawing contrasts between the hands of monkeys and men they disparage the monkey hand in an altogether unjust way. The most absurd statements are copied from book to book, and now it is almost impossible to read any more popular work which deals at all with the Primates without finding numerous ridiculous assertions that a visit to any zoological gardens will at once show to be untrue. Goodsir's statement that "no animal, not even the ape, can either fully extend or fully flex the elbow

joint "* has been freely copied and passed current as the truth. Humphry's assertion that the fingers of a monkey "do not admit of being separated so widely" (as Man's) "from each other in a fan-like manner" † and the very common statement that the thumb of the monkeys cannot be opposed to the rest of the digits form part of the stock-in-trade of inaccuracies so often put into books as though they were first-hand observations. As a matter of fact, it would be difficult to name any movement which is possible in the human hand which is not equally possible in the hand of the Old World monkeys, but any one may name a host of purposive actions habitual to Man, but which are not included in the usual repertoire of a monkey. The man who says the monkey has no power to oppose the thumb is, if he be speaking of Old World monkeys, simply confessing that he has not seen a monkey under such circumstances that the animal had occasion to perform the act; he certainly has never watched a monkey catching ants. When he says they cannot spread their fingers as far apart as is possible in the case of the human hand one can only infer that his acquaintance with living monkeys is extremely limited. The difference between the hand of a man and the hand of a monkey lies not so much in the movements which the arrangement of muscles, bones, and joints makes it possible for either animal to perform, but in the purposive volitional movements which under ordinary circumstances the animal habitually exercises. We shall look in vain if we seek for movements which a man can do and a monkey cannot, but we shall find much, if we look for purposive actions, which a man does do and a monkey does not. We may therefore attempt to reconcile our anatomical findings with the eulogies of the human hand so popular with some authors. We will agree with them as to the multitude, the beauty and precision, of the purposive movements of the human hand, as to its superiority in function over the hand of any other creature, and as to its great importance in determining the destinies of Man as a species. But they will certainly have to agree with us that the human hand is fashioned upon lines of the most basal simplicity, that it is a

* "Anatomical Memoirs," Vol. I., p. 237.

† "The Human Foot and the Human Hand," p. 155.

wonderful instance of the retention of a primitive structure in a higher animal, and that if we compare it, simply from the point of view of anatomical specialisation, with the forefoot of a horse, or a dog, or a cat, it is the lower animals which show the anatomical advance from a primitive condition which we retain. We will not agree with any one who lauds the human hand as an example of human anatomical advances and perfection ; but we will agree with any admirer of his own species who claims that as a cortically controlled structure the human hand affords striking evidence of Man's superiority over all the other members of the mammalia. It is not the hand which is perfect, but the whole nervous mechanism by which movements of the hand are evoked, co-ordinated, and controlled. In one thing Man certainly shows marked anatomical advance from conditions of basal mammalian simplicity, in one feature every monkey and ape compares but ill with him, and this is the wonderful development of the cerebral cortex. What we are admiring in the multitude of actions of the useful human hand is the human cerebral perfection, not the bones, muscles, and joints which carry out the complex volitions. Many must have been struck with this fact in watching the most highly skilled work performed by hands which we are apt to think are far too clumsy for the business, and we all know that it is not the finest hand, considered as an anatomical structure, that possesses the greatest dexterity. It is as useless to praise the human hand for the wonderful things the brain can find for it to do as it is to belittle the hands of the monkeys because so comparatively little cortical purpose is expressed in their habitual actions.

Voluntary, purposive movements are initiated in Man in a definite region of the cerebral cortex known as the Rolandic, pre-central, or motor area. The grey matter of the cortex in this region consists of quantities of nerve cells, buried among which are the so-called motor cells, giant cells of Betz, or ganglionic cells of Bevan Lewis. These nerve cells are the largest found anywhere in the cerebral cortex, and in general shape they vary from the conventional "pyriform" to "pyramidal." Each cell gives rise to several lateral processes as well as to an apical dendron which passes to the surface layers of the cortex,

and a great axis cylinder which runs straight from the surface of the cortex towards the centre of the brain, and thence to the spinal cord. These cells are distinctive of the portion of the brain which, when experimentally stimulated, produces movements of different parts of the body, and which, when destroyed by disease or injury, leads to an absence of movements, or paralysis. In Man this portion of the brain is a large field which occupies the cortex of the whole pre-central gyrus on the

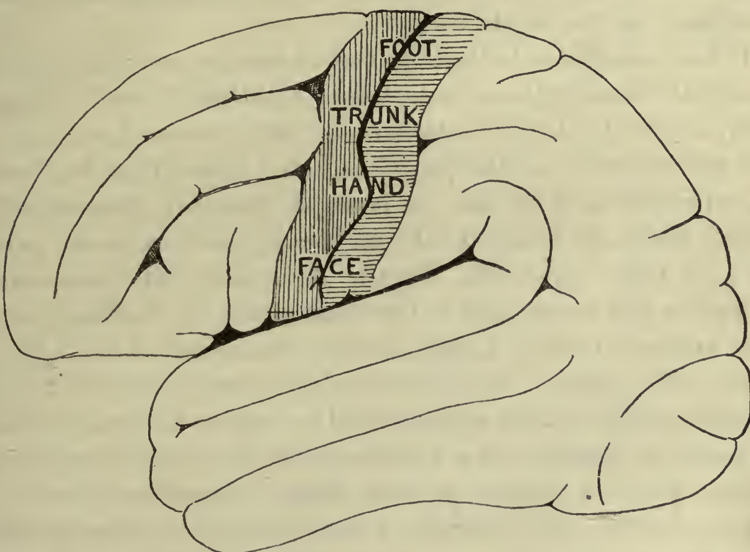

Fig. 107.—Diagram of the left side of the brain to show in broad outline the situation of the cortical areas around the fissure of Rolando.

lateral surface of the brain, extending downwards to the cortex of the island of Riel and upwards, over the superior margin of the hemisphere, to the paracentral lobule of the medial surface. Compared with the brain of any other animal, Man shows a particularly high development of this motor area, and of all those cortical fields adjacent to it which comprise its so-called association areas. The functions of this field of cerebral cortex are best appreciated by a study of the behaviour of animals which have suffered damage to some portions of their central nervous system. It is well known that many non-mammalian Vertebrates can initiate co-ordinated muscular movements in the complete absence of the brain, for after this organ has been

entirely destroyed movements of a complex nature persist in the limbs. A bird which has been altogether deprived of its brain can fly and run in a well-co-ordinated manner: its power of initiating muscular movements is lodged, not in its brain, but in its spinal cord. Even a mammal, such as a rabbit, may have its cortical motor area removed, and yet, far from being paralysed, it will continue to exercise all the movements which are normal to its species: its power of initiating muscular movements is lodged, not in the cortex, but in that basal ganglionic mass known as the corpus striatum.*

It has been stated by Kolmer that in the brains of many lower mammals—among them the hedgehog and the bat—no "motor" cells are to be found anywhere in the cortex. Speaking of the motor cortex in the pig, Campbell † states that he found no typical Betz cells, but "a layer of relatively much smaller cells" which he believed "to be the equivalents of the giant cells of Betz" (p. 273). In the dog these cells were more numerous and larger, and in the brain of the cat the motor area was marked by cells having all the characters of the typical giant cells of Man. In all the Simiadæ motor cells exist in a definitely limited motor area situated in front of a sulcus centralis, or fissure of Rolando, in a manner which is similar, though in a degree which is inferior, to that which is characteristic of the human brain. The findings of the histologists agree exactly with the results obtained by experimental physiologists, and evidently we are witnessing in this series of animals a steady evolution by which the function of movement is gaining what Hughlings Jackson termed "cortical re-representation." This means that, although movement is initiated at a lower level in the central nervous system (*i.e.*, in the corpus striatum), it is becoming re-represented in the cerebral cortex, and so is beginning to share in those great advances which cortical control confers. In Man this process has proceeded further than in any other animal, and in this process lies perhaps one of the most wonderful changes which have come about in the evolution of Man as an

* S. A. Kinnier Wilson, "An Experimental Research into the Anatomy and Physiology of the Corpus Striatum."—"Brain," Vol. XXXVI., 1914, p. 427.

† "Histological Studies on the Localisation of Cerebral Functions," p. 1905.

animal type. This change may be summed up crudely in a few words: Man has lost the use of his lower centre as a source for the initiation of the greater part of his limb movements, for he has completely translated the mechanism to his cerebral cortex. In order to understand this strange translation, we must attempt to realise, as far as may be, exactly what is implied in cortical re-representation and cortical representation. When a movement attains cortical re-representation, we may suppose that although initiation of the movement takes place in the corpus striatum, and may therefore be largely of the nature of a reflex, its performance will enter into consciousness, will be capable of being retained in memory, and will possibly become associated with memories derived from other sources of impression reaching the cortex during its performance. Moreover, the re-representation in the cortex will add the possibility of that great advantage which accrues from the accompaniment of memory, experience, and association, and which may be termed the capacity for education. We may express this stage of cerebral evolution by saying that the animal is cortically conscious of what the moving parts of its body are doing, and that it can remember what movements they have done, that it can associate definite acts of movement with definite impressions from the sense organs which streamed into its cortex while the movements were being performed, and that the experience gained and retained in this way may possibly lead to perfected modification of these movements as circumstances demand. A dog, with its cortical re-representation of movement, has a consciousness of certain of its movements and a memory of what actions it has performed; we might almost say it has a beginning of that psychical factor termed conscience. It is capable of recalling and associating its actions; even it may dream of actions by the building of cortical action pictures in its sleep consciousness. And, above all, as a result of experience, it is capable of perfecting its actions and modifying them to suit varying demands of time and circumstance. Nevertheless we know that a very large part of the repertoire of movement possessed by any lower mammal is carried on sub-cortically and partakes of the nature of a reflex. Only certain portions of

the body have gained cortical re-representation ; all the muscular acts of which a dog, for instance, is capable are not cortically represented.

Now, in Man the state of affairs is very different, for in the case of all those movements which we usually term voluntary movements the cortex is the only initiating mechanism which we possess. It is not merely that in Man there is a more complete re-representation of movement in the cortex, but that the corpus striatum has ceased to be a motor nucleus at all as far as voluntary movements are concerned. Voluntary movements are all initiated in the human cortex ; it only remains to determine somewhat more precisely what is meant when we speak of a movement as a voluntary one. We have seen that when this term is applied to muscles, in the manner which is customary in physiology, it is apt to be misleading, for it is not individual muscles of which the cortex takes cognisance. "Movements, not muscles, are represented in the cerebral cortex." A cortically represented movement is of a peculiar kind. It is not enough to term it voluntary. We may say that it is a movement of which the animal has definite knowledge, a movement which it can, so to speak, see and feel itself doing, a "pictured movement" or an "action pattern" which is realised by the animal. Now it will be noticed that in the chart of the motor areas of the human brain that portion which is allotted to the movements of the hand is not only particularly large, but it is situated in rather a curious position relative to the areas devoted to the movements of other parts of the body. It is probable that the well-known arrangement of the areas of cortical representation gives us a sort of skeleton map of the phylogenetic acquirement of cortical knowledge of the body. When an animal possesses cortical representation of the movements of a member, it has a knowledge of that member and a realisation of the different movements of which the member is capable; it can project the member into space and realise its position in space. The demand for this knowledge and the obtaining of this knowledge came into the lives of the mammals in a manner which a study of animal behaviour, checked by due regard for the condition of actual brain development, has rendered clear

enough. The work of Elliot Smith has made us familiar with the early importance of the sense of smell as the dominant guiding factor in the life activities of a low mammal. His work upon the development of the cortex (see especially Presidential Address, Section H, British Association Report, 1912) marches in absolute harmony with the observations made by many workers upon animal behaviour. A low mammal first gains its impressions of the world by its sense of smell; it tests the world with its nose. Not only is the olfactory sense a guiding one, and one demanding a large share of cortical representation, but the tactile sensations of the snout region, of the lips and tongue, are soon added as sources of information wherewith to learn of novel objects. The snout region therefore gains cortical representation as a feeling and moving part of the body. Now elsewhere (see "Arboreal Man") attention has been called to the fact that when once a primitive mammal has taken to an arboreal life the eyes become the sense organs which replace the nose as the dominant informative special sense, and that the hand, emancipated from the duties of bodily support, becomes the great testing member of the body. The primitive arboreal animal learns of the world and tests novel objects with its eyes and its hands. A large visual area in the cortex and a large area for the sensations and the movements of the hands are therefore typical of such an animal. It is notable that in the human brain the large hand area is situated immediately adjacent to the older area in which sensations and movements of the face are represented.

There is, therefore, a curious order in cortical representation of action patterns of the members of the body, and this order we may picture as representing the sequence of the phylogenetic acquirement of knowledge. Representation does not take place in strict anatomical plan; we do not pass, in going upwards on the pre-central gyrus, from the nose and mouth to the neck, shoulder, elbow, wrist, and hand. The knowledge of our moving parts is arranged with the arms, so to speak, reversed, for next to the head come the hands, then the wrist, elbow, shoulder, and the trunk is reached once again. But when the trunk is reached the march of representation proceeds in an orderly

anatomical manner, the trunk, abdomen, hip, thigh, knee, leg, ankle, foot, and toes having their motor and sensory areas in regular order as the pre-central gyrus is ascended. The area for the perinæum appears to be situated on the most distal part of the area where the motor cortex has passed to the medial aspect of the hemisphere on the paracentral lobule. Now this is a very curious arrangement, and it must be remembered that it represents the acquirement of conscious concrete knowledge of moving parts, and that both on phylogenetic and ontogenetic grounds there is every reason to believe that it depicts the actual historic sequence of the acquirement of this knowledge. We may therefore imagine that when once the testing hand and the eye had obtained their large share of cortical grey matter they were the instruments by which the knowledge of the rest of the body as a moving thing became added to the cortex. It is the hand and the eye that have given Man such intimacy with the external anatomy of his own body as has ensured him recording in the cortex of his motor area "action patterns" which represent the pictured movements of practically every moving part. More than this, it has caused the whole mechanism for initiating these pictured movements to become entirely cortical, and the functions of the corpus striatum as a motor nucleus are lost in Man. We may therefore say that not only has the hand an extraordinarily large share of cortical representation, but it has been a pioneer in leading to the representation of other parts of the body.

Necessarily there are some important outcomes of this human development of cortical pictured movement areas. We have seen that the motor area may be removed in a rabbit without producing any paralysis, or even any obvious change in the animal's behaviour; but the same operation carried out on a series of other mammals shows that with increasing representation increasing damage is done to the motor functions of the animals. In monkeys removal of the motor area produces well-marked paralysis, but later on this is to a great extent recovered from; but in monkeys, as in Man, the recovery of the hand is the least complete and the longest delayed. In Man, when the motor area of one side of the brain is destroyed or

damaged by some pathological process, the well-known paralysis of one side of the body, termed hemiplegia, is produced. In Man recovery probably represents no more than the restoration of parts of the brain originally somewhat damaged, but not destroyed, by the lesion. Whatever recovery takes place after a "stroke," the ultimate damage inflicted on the hand vastly outweighs that remaining in the lower extremity.

Then again, since the movements of our limbs are initiated in our cortex, they can never become reflex in the same way as the familiar reflexes carried out in the lower cerebral centres and in the spinal cord. It is customary to speak of such repetitive movements as walking, playing the piano, or regulating a machine, as being carried out as reflexes with long familiarity. But, in the sense that any of these complicated movements are ever relegated to lower centres, the use of the word "reflex" is quite incorrect. Were they ever to become mere reflexes, they would be performed in cases of hemiplegia as other reflexes are. It is difficult at first sight to believe that such a process as the ordering of the various movements in walking is a cortical function. Walking appears to be carried on in the absence of all cerebration, and yet it is a curious thing that even when we may imagine that walking is purely mechanical many of us will confess to an unsuspected consciousness in the process. I believe that there are few people who are utterly indifferent as to the junctions between the paving stones in so apparently mechanical a thing as a walk along a paved street and few who do not plan some way ahead which shall be the foot to step down when the edge of the kerb is reached. In some forms of so-called insanity the consciousness of the movements of walking is a very striking thing. It is still more easy, with some consideration, to realise that no repetitive movements of the hand are anything other than cortical in origin. Even the woman who knits with the deadly regularity of a machine while employed in some other occupation is initiating every movement from the motor area of her cortex, and a "stroke" which damages nothing but the cortex and the motor paths that lead away from it would certainly put a stop to this activity.

It is also for the reason that in us the ordering of movements

is so strictly cortical, and that the cortex is pre-eminently that part of the nervous system which is susceptible to education, that the human baby has to " learn " so much which comes naturally to the lower animals. The human baby has to educate a cortical function; the lower animal has merely to exercise an anatomically arranged reflex. Many philosophers have speculated upon the fact that Man alone among the mammals has to learn to swim. One thing may possibly have struck any one who can remember the dawn of his ability to swim, and that is that there comes a period when, with perhaps no gain whatever in skill of movement, the individual realises that he can swim, can, so to speak, " see himself doing it." Again, he may remember that, having attained to the stage of realisation that he can swim, he can educate his powers of execution, but he may also have confidence that, even if he does not perfect them, he will never return to the state of being unable to swim at all. He has definitely obtained that cortical scheme of associations which we imagine to constitute a pictured movement, or an action pattern, for swimming.

At times, and under unusual circumstances, it is possible for the individual to lose his pictured movements by a process which appears to resemble a dissolution into oblivion of his stored-up action patterns. Of this nature are the thousands of cases of so-called " functional " or " hysterical " paralysis which have occurred during the War. Owing to some cause, which may be termed a suggestion, the patient loses the use of some part. A bullet, say, has passed through the flesh of his right arm, and although it has done no damage whatever to any structure other than the biceps muscle and the skin, his right wrist and hand become completely paralysed. He may be told that his hand will get all right, and that he should use it, but the attitude he takes towards such advice may be translated by the expression that " he can't see himself doing it." Many strange rituals are supposed to play their part in the treatment which is known as psycho-therapy, but, so far as hysterical paralysis is concerned, it may be said to consist in an attempt to restore the vividness of action pictures which have faded from the cortex.

Now, although so much of the sum total of muscular movements has become a cortical function in Man, there still remain certain movements of which we have no sort of pictured conception, and the initiation and ordering of which is therefore still lodged in the lower centres of the brain stem or even in the spinal cord. We have no concrete picture, no action pattern, of the movements of our viscera ; our hearts and intestines move in a way which is unfamiliar to us; and these so-called involuntary movements, subserved by the involuntary muscles, are not represented in, nor initiated by, the cerebral cortex. But there are some actions in which voluntary muscles play their part, but which are still unpictured actions, and therefore lodged in a nervous centre lower than the cortex. Previous reference has been made to this subject in Chap. XV., and there the act of sneezing was instanced as a movement largely carried out by voluntary muscles, but the initiation of which was lodged in the brain stem, and not in the cortex. We might also cite coughing and the complex act of stretching and yawning when carried on purely as a reflex, due to the fulness of the dependent veins and the venous condition of the blood. In the act of stretching, the arms are first stretched out straight and raised from the trunk at the shoulders, and obviously these acts are strikingly like those which the cortex is capable of initiating as ordinary pictured movements. A man may have a hemiplegia which affects one arm; he may be utterly incapable of producing movements in the arm when asked to do certain definite acts; he is truly paralysed. But when he wakes in the morning he will yawn, and may accompany this yawn by stretching, a movement in which his paralysed arm may share. It is possible that the night nurse may witness this performance and think the less of the reality of his paralysis. But it is all genuine enough. When the man is asked to raise his arm from his side he attempts to produce a pictured action by the exercise of a cortex the connections of which are so damaged that the muscles cannot receive the message of volition. When he yawns and stretches, the cortex does not come into play, and the centre in the brain stem, remaining undamaged, may still activate the very muscles which previously failed to respond to the volition.

It is this differentiation in the place of inception of muscular movements that produces the well-known clinical phenomenon of a voluntary muscle being paralysed for one action and yet remaining free to perform another, and it must be remembered that it is the difference in the quality of the action that determines the difference in the site of inception.

CHAPTER XXII.

THE MOTOR PATHWAYS.

WE have already noted that the Betz cells which are characteristic of the motor area of the cortex, and which there is every reason to believe are the agents subserving the movements of volition, are nerve cells possessing a series of processes given off from the cell body.

A series of fine lateral processes and a stouter apical dendron bring the cells into relation with other cortical elements, and, one assumes, act as the links in that cell complex which constitutes an action pattern. In addition to these processes is one great axis cylinder, or neuraxon, a prolongation of the cell body, which passes into the centre of the brain on the first stage of its journey towards the spinal cord. This journey ends when the axis cylinder comes into connection with the spinal motor cell, or cells, upon which it is destined to exert its influence. The more minute details of the course and connections of the motor path will not be entered into, only the broader outlines of the main tract being indicated in order to obtain a rough picture of the cortical control of the hand as a motor agent of the will.

Upon turning from the surface towards the centre of the brain the axis cylinders of the Betz cells, from the hand representation area of the cortex, stream into that central white mass which composes the bulk of the brain substance and is termed the *centrum ovale*. In the centrum ovale are not only fibres such as those with which we are dealing, which pass from the brain to distant stations, and are therefore termed *projection fibres*, for a large bulk of the white substance is composed of short fibres, which run between neighbouring stations within the brain itself, and are known as *association fibres* and *commissural fibres*. The long projection fibres of the motor cortex gather themselves together into a thick band, elongated in the long axis of the brain, and flattened from side to side in order to squeeze through

the narrow interval between the great grey nuclear masses lying at the base of the brain. As the axis cylinders arise from the Betz cells in the motor cortex they are arranged in linear series, the long axis of which is nearly vertical. In this series the axis cylinders destined to exert their influence upon the movements of the foot are highest in position, and those destined for the movements of the face are lowest. As this bundle of fibres readjusts itself to stream between the basal nuclei a twist is put on the strands composing the tract, and the lowest fibres take the front place in the band which is emerging from the brain stem. The large constituent of this tract which is destined for the hand movements is therefore situated slightly below the mid-point of the vertical fibre band immediately deep to the cell mass of the motor area, and slightly in front of the mid-point of the sagittally elongated bundle between the basal nuclei. In the first situation the fibres for the leg movements are above, and in the second behind, the fibres destined for arm movements. It is the fanwise readjustment of these down-streaming fibres which gives rise to that appearance of the white matter of the centrum ovale which has earned the name of *corona radiata*. The portion of the tract which is insinuated between the basal nuclei is known as the *internal capsule*, and it is compressed between the lenticular nucleus on the outer side and the caudate nucleus and thalamus on the medial side. In the recess between the caudate nucleus and the thalamus the internal capsule is kinked inwards towards the cavity of the third ventricle. This kink is known as the *genu*, and the hand fibres run downwards just behind the genu. Below the ganglia the motor pathway emerges from the cerebrum, forming a part of those rope-like structures known as the *cerebral peduncles*, or *crura cerebri*. The motor tracts are exposed on the surface of the peduncles, and constitute the middle portion of the band of fibres which clothes the surface of the peduncle, and is known under the name of the *crusta*.

Next, the tracts from either side of the brain approach close to each other as the two peduncles are bound into a common stem by the transverse fibres of the pons. In the pontine portion of their course the longitudinally running motor tracts

become somewhat broken up into separate bundles by the numerous fibres which run from one side to the other across the course of the tracts. At the lower border of the pons, however, when the transverse fibres come to an end, the motor tracts emerge again as two well-marked surface columns known as the *pyramids*, or anterior pyramids, of the medulla. Upon the medulla the two pyramids stand out boldly. They are separated from each other by the anterior median fissure of the medulla. If this fissure be opened by pulling the two pyramids apart, it will be found that about one inch below the lower border of the pons the cleft is interrupted by the passage from one side to the other of the axis cylinders contained in the pyramids. This is the *decussation of the pyramids*, and the anatomical condition is brought about by the passing of the motor tract which was in the left pyramid across the middle line to the right side of the spinal cord, and *vice versâ*. Having now reached the spinal cord, the axis cylinders of the Betz cells of the right pre-central cortex find themselves upon the left side, and contained in the so-called *crossed pyramidal tract*. The axis cylinders from the cortical hand area run in this tract until they descend to the level of the origin of those nerve roots from which are derived the motor nerves of the muscles acting on the several joints of the hand. The four lower cervical segments and the highest dorsal are those from which the motor outflow to the fore limb takes place, and the " nerves " which supply the muscles are the axis cylinders of cells which lie in the grey matter of the so-called anterior horns of the spinal cord. Around these spinal cells the axis cylinders of the Betz cells come to an end by passing from the pyramidal tract to the anterior horn and breaking up into the fine filaments of the anterior horn cell synapsis. We have therefore an axis cylinder, neuraxon, or cell prolongation which runs unbroken from the cortical motor cell through the tissues of the brain and spinal cord to end as arborisations around other " motor " cells in the anterior horn of the grey matter of the cord. This portion of the motor pathway is known as the *upper motor neuron*. The length of the upper motor neuraxon, or axis cylinder of the motor cell, naturally varies with the function, for a greater length of the cord has to be traversed by

the neuraxons destined for the cortical control of the movements of the leg than is the case with those for the hand. Not only does this hold true for the cord, but it also applies to the brain, since the foot centre is the highest in the pre-central cortex, and neuraxons from it have to run a longer course before emerging from the brain itself. The upper motor neuraxons for, say, the arborisation around the anterior horn cells of the second sacral segment, have to traverse the maximum course both within the brain and within the cord. The upper motor neuraxons destined for the cortical control of the motor supply for the face have the shortest course to run, since they stretch only from the lower end of the cortical motor area to the outflow of the lower motor neuron in the pons. It is this great difference in the necessary lengths of the upper motor neuraxons that is largely responsible for the great difference in size of the Betz cells in different fields of the motor cortex. The longer the axis cylinder has to be, the bigger will be the parent nerve cell. It should also be noticed that the axis cylinders of the Betz cells which are in the highest portion of the cortex become the posterior fibres in the internal capsule, and maintaining their posterior position in the cord, they pass forwards last of all from the pyramidal tract to the anterior horn cell. The upper motor neuron destined for the hand occupies in all respects an intermediate stage, and its parent motor cells are neither the smallest nor the largest of those which characterise the pre-central cortical field.

Now the most striking thing concerning the anatomical features of the upper motor neuron is that it is a crossed pathway. By far the greater number of neuraxons change from one side to the other at the decussation of the pyramids; but certain of them do not cross here, and are continued as the smaller tract in the cord named the *direct pyramidal tract*, in distinction to the main tract, which is termed the crossed pyramidal tract. But it must be understood that in applying the term " direct " to this tract it is not intended that the name implies an uncrossed pathway between the cortex and the anterior horn cell. The direct pyramidal tract consists of neuraxons which do not cross at the main decussation of the pyramids, but effect their passage from one side to the other at different levels by the route of the

anterior commissure of the cord. In this way the crossing of the motor path from the cortex to the limbs is made complete. The right Rolandic area therefore presides over the movements

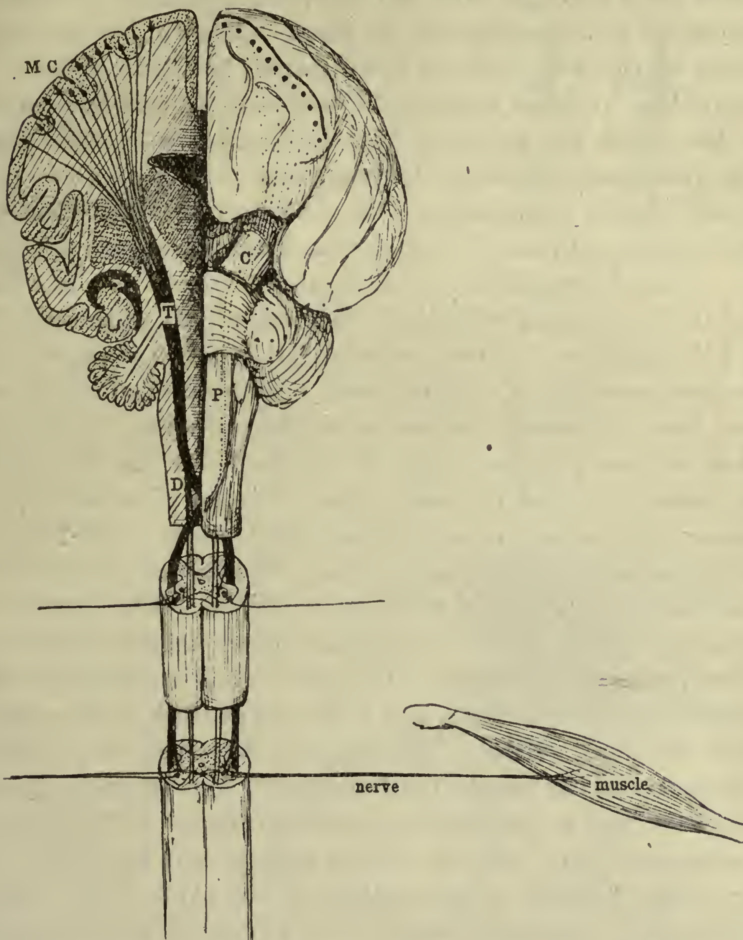

FIG. 108.—The motor pathway seen in diagramatic coronal section of right side of brain. MC = Motor cortex. T = Motor tract below the internal capsule. D = Decussation. C = Crus cerebri. P = Pyramid on undissected side of brain.

produced in the left hand, and the left area over those produced in the right hand. Bound up with this curious condition of crossed cerebral control of the movements of the body is the problem of right-handedness. The right-handed man is naturally one who uses the motor area of the left cerebral cortex with far

more efficiency than he does the right-sided area. In attempting to solve the problem of right-handedness we could adopt two alternative lines of inquiry : either we might seek for some cause which made the right hand and arm more efficient as anatomical structures, or we might look for some explanation of the dominance of the left cerebral hemisphere. The first method of attempting to throw light on the causation of right-handedness is that which has generally been fashionable with anatomists. The unilateral position of the heart and great vessels has been invoked in the explanation. The difference in origin from the aorta of the right and left sub-clavian arteries has been appealed to. It has been said to be due to an "instinct"; it has been said to be correlated with the "slight superiority of the right leg and the right eye." Many other causes, mostly associated with the gross anatomy of the limb, have been mentioned by authors who have interested themselves in this question. Now, from what we have previously seen of the hand as a physical organ, we should not look for such a line of inquiry to yield much success, for we have come to regard distinctions of the hand as being due to cerebral advances rather than to local perfection of anatomical structure. A much more promising field is therefore opened up when we come to inquire into the relative conditions of the right and left halves of the brain. It is to this side of the question that Elliot Smith and other recent workers have given their attention. Briefly, we may say that there is a normal asymmetry of the human head and brain, an asymmetry which manifests itself in one way by the curious course of the superior longitudinal sinus and the lateral sinuses, and in another by the actual contour of the outline of the skull. This human asymmetry is wholly in favour of the left side of the brain, and although it is said that "there is no evidence that the right hemisphere is the heavier in left-handed people" (Quain's "Anatomy"), there is certainly evidence that in them the normal asymmetry of the skull is reversed. What may be the cause of this primary cranial asymmetry is a problem into which we cannot here inquire, for it, in its turn, is probably involved in the larger question of the general tendency to local asymmetry in the two-sided embryo.

So far we have considered the upper motor neuron as a single derivative of a cortical cell, which ends as an arborisation around another cell situated in the grey matter of the anterior horn of the spinal cord. We must enlarge this view in two directions. First, the number of neuraxons in the pyramidal tracts is not so great as the number of motor cells in the anterior horns, although it corresponds accurately enough with the number of Betz cells which are congregated in the cortical motor areas for the trunk and limb. This means that more than one anterior horn motor cell is brought under the influence of the terminal arborisations of the neuraxon of each cortical cell. Then again, the upper motor neuron comprises, for all practical purposes, more than the neuraxon of the motor cell, or, in other words, more influences are exerted along the upper motor neuron in the process of initiating an ordinary voluntary movement than are carried from the motor cortex along the pyramidal tracts. In the language of Sherrington (for further details see "Integrative Action of the Nervous System," 1906), the upper motor neuron, considered as an entity, consists of a number of "private paths." At least four such paths are definite constituents of the upper motor

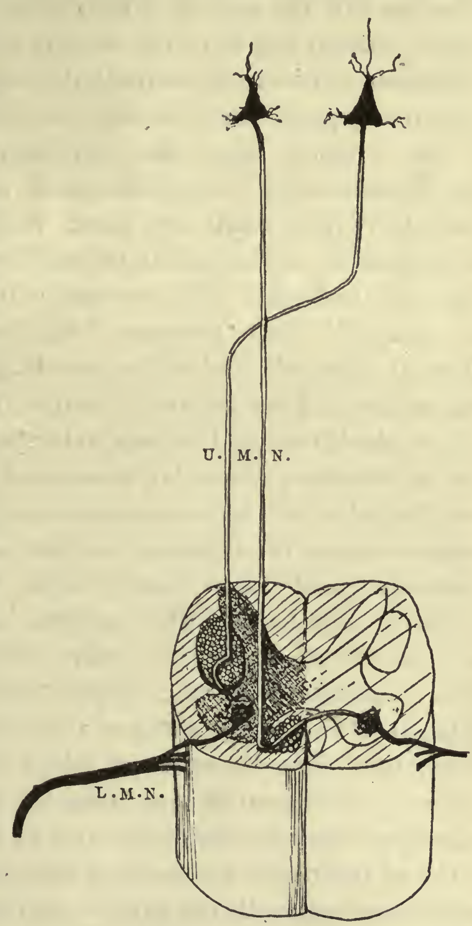

FIG. 109.—Diagram to show the two elements in the motor pathway. U.M.N. = Upper motor neuron. L.M.N. = Lower motor neuron.

neuron complex. First is the great pathway from the cortex that we have already followed. From the point of view of function this cortico-spinal tract is the most important of them all, since it is the path by which volition is carried to the lower motor neuron, and so to the moving part; and when by injury or disease it becomes interrupted, paralysis of a definite kind, known as upper motor neuron paralysis, is the result. Next is the pathway from the cerebellum to the anterior horn cell, known as the cerebello-spinal tract, and the influences carried by this road are those which produce the proper co-ordination of the action of volition. The corpus striatum, although in Man "its true motor function has gone, never to return,"* still possesses its private pathway to the anterior horn cell, and still exerts its influence upon voluntary movements. This pathway is that known as the lenticulo-rubro-spinal tract, and damage to it produces a tremor in carrying out a voluntary muscular movement. The last of all the private paths is the very curious one by which the vestibular system exerts its influence on the anterior horn cell. This vestibulo-spinal tract takes origin from Deiter's nucleus, which is situated in the medulla in association with the centres of the vestibular nerve. The influence exerted by this constituent of the upper motor neuron is that of balancing, and in its absence there is produced a staggering (titubation) type of movement which is characteristic. For the proper performance of any muscular act of volition four influences, carried from various centres in the brain by four private paths of the upper neuron, are necessary. When we desire to grasp an object with the hand or perform a fine movement with the fingers the cerebrum, the cerebellum, and certain grey masses of the brain stem are harmoniously involved. The absence of any one of these influences produces a definite defect in the resultant movement, but the absence of the influence of the cerebral cortex prohibits the production of pictured movements altogether, for it results in paralysis of the upper neuron type. In this type of paralysis, which is that present in ordinary hemiplegia, the muscles which are unable to take part in pictured

* Kinnier Wilson, *op. cit.*, p. 489.

movements are still able to act in movements which are not initiated in the cortex. The muscles are not paralysed for reflex movements; in fact, as this is now their only possibility for action, their participation in reflexes becomes increased. Such paralysed muscles do not degenerate, they do not lose their tone, nor do they cease to respond to stimulation by the faradic current. They are simply muscles which the cortex cannot use for the performance of a cortically desired movement.

So much for the upper motor neuron. The lower motor neuron starts as a motor cell in the grey matter of the anterior horn of the spinal cord, and terminates as a motor end-organ in a voluntary muscle. Like the upper motor neuron, this is an anatomical entity consisting of a motor nerve cell and its neuraxon, but in this case the neuraxon runs in company with others as a free " nerve " instead of being incorporated in the substance of the spinal cord as a spinal " tract." The neuraxon of the lower motor neuron emerges from the antero-lateral groove of the spinal cord as one of the anterior or motor nerve radicles. It joins with others into a bundle of neuraxons which constitute the anterior or motor root of the spinal nerve arising from that segment of the cord. The anterior root of the spinal nerve then runs outwards, away from the spinal cord and vertebral column, and, becoming combined with the fibres of the posterior or sensory root, forms an element in the mixed (motor and sensory) spinal nerve which (in the case of the nerves for the hand) runs across the root of the neck to reach the arm.

From here onwards the course of the lower motor neuraxon becomes complicated, and it is necessary to mention some of the causes of this complication. If the lower motor neuraxons of any one segment of the cord passed simply to a definite group of muscles derived from the same segment, and all the muscles of this group performed the same action, then the motor nerves derived from any one anterior root might run a simple course to the muscle group, and so function in producing one definite movement. But this ideally simple state of affairs does not exist in any higher animal. Muscles are great phylogenetic wanderers. They change their origins and their insertions as different poises, proportions, and activities of the animal body

demand it. Their actions upon the limb are therefore altered with their phylogenetic shiftings. It therefore happens that the muscles which we might assign to any primitive segmental group (even if such a thing be possible in the limbs of a higher animal) are, in the adult body, represented by a scattered series of muscles possessing different attachments and different actions. In this way it comes about that the motor neuraxons of any one spinal root have to supply muscles varied in site and in function. Moreover, single muscles may draw their nerve supply from the neuraxons of several segments, and muscles performing the same movement and involved in producing the same act of volition may derive their nerve supplies from different spinal segments. Again, the lower motor neuraxons, having once become mixed up with the sensory fibres of the posterior root to form the common spinal nerve, have in some measure to sort themselves out again. The ultimate nerves which they form are described as motor nerves : but it must be remembered that no such thing exists as a nerve which contains nothing but the neuraxons of anterior horn spinal cells ; for, as Sherrington has shown (*Jour. Phys.*, Vol. XVII., 1894–15, pp. 211—258), in all muscular nerves, one-third to one-half of all the myelinated fibres are connected with cells of the posterior root ganglion. All these complexities lead to an extensive coming and going of the neuraxons from the different roots supplying the limb. Readjustments have to be made, and these are affected by the formation of plexuses. Into the plexus run the spinal nerves of those body segments from which the limb buds grow. The lower motor neuraxons are therefore carried into the plexus along with the sensory fibres by different spinal nerves, in the plexus they become sorted out and led into certain mixed nerves which traverse the limb, and from these they come off again as the motor nerves to the several muscles. For the arm, with its pentadactylate hand, there are, as we have already pointed out, five spinal nerves entering into the plexus. The fifth, sixth, seventh and eighth cervical nerves, and the first dorsal nerve join into the brachial plexus, and from the plexus the named nerves of the arm run to the various muscles and to the skin. A description of the brachial plexus is not entered into here;

it is only necessary to realise that it is a junction by which the lower motor neuraxons arising in the anterior horn cells become despatched to a wide series of muscles. We must also remember that every lower motor neuraxon present in the motor nerves as they are found in the limb are the " public paths " along which the influences carried in the several " private paths " of the upper motor neuraxon are taken to the muscles.

The upper motor neuron may be injured or destroyed, producing paralysis of a very definite type, which we have described. The destruction of the lower motor neuron also produces paralysis of those muscles to which the particular neuraxons which have been destroyed are furnished. In lower motor neuron paralysis the muscle loses its tone, it degenerates, it loses its response to the faradic current, and may be regarded, not as a muscle which is merely out of touch with the mind, but as a muscle cut off from its source of life—a muscle which will ultimately cease to exist as such. The termination of the lower motor neuraxon in the muscle is effected by the medium of a motor end-organ. These end-organs are of more than one variety, and the names that have been assigned to them sufficiently indicate their type. The " bush " end-organs of Kühne, the " plates " of Rouget, and the " hillocks " of Doyère are all varieties of the termination of the motor fibres in muscle, and are distinct from the " muscle spindles," etc., which form the end-organs of sensory nerves in muscles.

CHAPTER XXIII.

The Hand as a Sense Organ.

Many of the processes of development which are called into play in the formation of the human embryo are so strange, and so seemingly meaningless, that the student is apt to lose his capacity for being surprised at the findings of embryologists, and more than this, the very multiplicity of problems tends to dull that spirit of inquiry which, above all things, the teaching of anatomy should instil into the student's mind. It is probably for this reason that so few people feel any astonishment when they learn for the first time that the whole of the central nervous system is merely an inturned portion of the general surface of the embryonic body. The first beginnings of the neural axis comprising the brain, spinal cord, and every other part of the bewilderingly complex adult central nervous system are manifested as the sinking in of a linear dorsal portion of the ordinary epidermal covering of the embryonic body. Later on the mid-dorsal depression, or neural groove, deepens. It becomes buried in the tissues of the embryonic body, and during this process the sides of the groove (neural crests) fold over and, meeting in the middle line, convert the neural groove into a hollow neural tube, now sunk beneath the general surface of the body. It is also from this same general epidermal covering of the embryonic body that the special sense organs of smell, taste, sight and hearing are developed. The rest of the surface covering of the embryo, left over after the central nervous system and the special organs have been differentiated, becomes the skin, and all its adult derivatives, such as hair, nails and teeth. Now this is a very curious thing, that our brains and the whole of our nervous systems should be developed from that embryonic layer which, when remaining in its original site, simply gives rise to our skin. It would seem that we should not unduly strain the logical deductions which may be drawn from a study of embryo-

logy if we regard the central nervous system as no more than a buried portion of skin, or, alternatively, we may look upon the skin as an exposed portion of the central nervous system. Certainly we shall be upon safe physiological grounds when we regard the skin as the greatest and most ancient sense organ of the animal body. The skin of every animal is a sensory covering which enables the animal to learn about its surroundings. It is the outside of the animal, and forms the medium by which the outside world is appreciated. One can conceive of a lowly animal having no other sense wherewith to learn about its environment save that of touch present in the skin of its simple body. But as soon as the animal begins to progress through the world in a definite direction, that end of the body which is directed forwards will need more information, since it comes first into contact with the objects of the outer world. In this way the skin at what we may consider as the head end of the body will become specialised into a more sensitive area, which we may picture as the precursor of the great cephalic sense organs of the higher animals. But the sense organ is of but little use to the animal if it is unable to take advantage of the information derived from it. Connection between the sense organ and the deeper tissues of the body is needed in order that the animal may react appropriately; a sensory impression must be able to produce a motor response. Cells from the surface layer may take up a deeper station in the body and so maintain connection with, and pass on stimuli to, the cells which are specialised for producing movement. This arrangement may be regarded as indicating a beginning of that curious process whereby cells from the surface of the body—from the layer which learns and knows about the world—pass directly into the depths of the body to act as a link between the cells knowing of the outside world and the cells responsible for producing the movements of the animals. These go-between cells in us are those limited to the mid-line of the dorsal region of the embryo, which sink in as the neural groove and form our central nervous system. Of the neural groove the anterior position is the largest and best developed, and this, by reason of the fact that as the animal progresses the anterior end of the body goes in advance, learns first of the out-

side world, and so develops specialised areas of the outer covering known as sense organs. The fact that motion in a uniform direction leads one end of the body to bump into external objects demands a sensitiveness of that end of the body and determines the site of that more elaborated portion of the nervous system which is termed the brain.

Our central nervous system we will therefore regard as a portion of our skin surface which is buried in our bodies for the purpose of keeping up connection between those cells which know of the outside world and those cells which act upon this knowledge.

Our brains we will picture as being simply the enlarged anterior end of this central nervous system, elaborated because the anterior end of the body is, so to speak, the business end, and is armed with those sense organs that first meet the world as we move through it.

It would, from a consideration of their manner of development, be quite legitimate to speak of an internal nervous system and an external nervous system, the one being hidden in our bodies and the other exposed upon the surface for all the world to see. This is no place to dilate upon such a theme, but he is the wise physician and philosopher who realises that in regarding the external appearance of his fellow-men he is studying the external nervous system and not merely the skin and its appendages.

When we turn to a consideration of these things in a primitive type of mammal we see the great importance of that sense organ which is developed at the tip of the forwardly moving end of the animal's body. This sense organ is the olfactory organ. It is the sense of smell which guides the primitive mammal about the world. But more information is needed than that which is derived from the scent of an object, and further knowledge of unfamiliar surroundings is derived from the sense of touch. Touch-testing is a business which is carried out in very different ways by different animals. There is no doubt as to the manner of touch-testing with most primitive mammals, for it consists of the familiar process which may best be described as "nosing" objects. The great fifth nerve area of the snout is the tactile field upon which the lower mammal relies for its information.

Vibrissæ, or "whiskers," and sensory papillæ are added to this nosing area to heighten its tactile sensibility; the great Gasserian ganglion becomes a sign-post of the importance of the trigeminal nerve, and even in the absence of vision such an animal is kept informed of its surroundings by the sensation of touch derived from its muzzle. Special sensory nerve terminations of the snout nerves have been described in several mammals: Eimer has described them in the mole, Ranvier in the pig, and Botezat in the dog, and the extraordinary snout sense organs of the bats have attracted the attention of many workers.

When a lower mammal becomes clothed in dense hair the tip of its nose is, as a rule, naked. Not only is it naked, but in animals which depend almost altogether upon olfactory impressions in hunting their food or avoiding their enemies, the tip of it is kept constantly moist. In animals which have come to depend more upon the information derived from the sense of sight than from the sense of smell the tip of the nose is usually dry. This moistening of the muzzle in scent-hunting animals is merely an adaptation for detecting the direction of air currents: the sailor who wets his finger to find out which way a very light breeze is moving is merely imitating the naturally wet nose of the canine hunter or the bovine hunted. When a mammal becomes protected by the thickness of its skin, the skin of its muzzle still remains sensitive. The snout of the tapir is that animal's great tactile organ, and the trunk of the elephant might almost be regarded as an extreme specialisation of the same thing.

Snout-testing is, however, the hall-mark of the terrestrial mammal, for once the solid earth is left by climbing, flying, or swimming, the olfactory sense ceases to be the great guiding sense, and visual impressions become more and more important. With a clambering or climbing animal it is not the nose which learns about the world and the muzzle which tests new objects, for the eyes supplant the nose, and the prehensile hands, no longer mere organs of support, usurp the functions of the muzzle. This simple combination of circumstances has made a huge advance in the status of mammals. The novel object to be examined is tested by the hands whilst it is under the observation

of the eyes. A dog may test a novel object by sniffing it and touching it with its nose, but a monkey tests it by picking it up in its hand and examining it. Even a monkey may so far forget itself as to touch a novel object with its nose, but no one ever saw, say, a dog inquiring into the properties of some strange object by taking it with its paw. In the arboreal mammals, therefore, the hand has become the greatest of the cutaneous sense organs. It is that special part of the general sensitive body skin which is elected by the animal as the organ which shall teach it of the qualities of its surroundings. In Man it is more highly specialised for this function than it is in any other animal. It is perfectly obvious that, when we follow the history of touch-testing in the mammals, we should look upon the hand not only as a member which is useful for grasping and performing various kinds of work, but we should regard it also as a highly specialised sense organ. There are many curious circumstances brought about by abnormal and emotional conditions which clearly give us a hint that in considering the pathology of the hand we must always have regard to the fact that it is no ordinary member, but is a specialised portion of the sensory side of the nervous system which may manifest changes only to be explained by the fact that it is our dominant organ of tactile sensibility. Everything that we wish to learn about a novel object which we cannot glean by our other sense organs we learn by hand-testing. We learn of its surface texture, if it be rough or smooth, and the hundred other qualities of surface easily appreciated but not easily named. We learn its shape and its dimensions; we judge if it be hard or soft. We estimate weight and draw conclusions as to its solidity, and we appreciate the fact that it is either hot or cold, or of about the same temperature as that of our own hands. There is little that a blind man may not learn about an object by subjecting it to an examination with his fingers. As a rule, in this process of hand-testing, it will be noticed that the index finger plays a prominent part. No better example could be given of the index finger manifesting the true function of a sense organ than the performance of an ordinary clinical digital examination. If the clinician be watched as the examination proceeds it will be realised that the

examining index finger is standing in the same relation to the cortex as does the listening ear or the searching eye. If we wish to distinguish some object in the dark, or with our eyes shut, the thumb, the index finger, and the radial aspect of the middle finger are most called upon to furnish us with knowledge. Of our special tactile sense organ these are the most specialised members. As we shall see later on, the contact surfaces of these digits are median nerve territory, and we may therefore say that the median nerve is the channel by which the large bulk of our informative sensory stimuli is carried to the brain. In the primitive mammal the fifth cranial or trigeminal is the great informative nerve which conveys tactile knowledge of the environment to the cortex of the animal; in the arboreal animal, and especially in Man, the functions of the fifth nerve are usurped by the median. In dealing with the median nerve, therefore, we shall do well to bear in mind this fact. We have said that the clinician should regard the hand as a sense organ; we can now suggest that he should regard the median as a very special nerve—a nerve by which a great bulk of the knowledge of our environment is wont to come to our cortex. In dealing with the peripheral nerves we shall see that this hypothesis that the median nerve is a peculiar one is fully justified by clinical facts.

In dealing with the sensibility of the hand it is not enough to distinguish the sensations produced as those of touch, pain, heat and cold, etc., for the work of Head ("Brain," 1908, etc.) has made it clear that cutaneous sensibility may be divided into two types, which he termed epicritic and protopathic sensibility. Epicritic sensibility comprises light touch, the appreciation of a very gentle movement of cotton wool drawn lightly across the skin, the appreciation of temperatures between 26° and 37° C., and the ability to recognise two separate, but simultaneous, contacts. Protopathic sensibility includes the more crude sensations of pain as evoked by the prick of a sharp needle and greater degrees of heat and cold. These forms of superficial sensibility must be distinguished from deep sensibility, such as the appreciation of pressure, the sense of position of joints, and the sense of vibration. Again, the stereognostic sense, or the ability to recognise the size and shape of objects, is a definite

complex made up of elements of both deep and superficial sensibility. Such a classification affords a basis for all investigations upon the peripheral nerves, and, as we shall see later, different peripheral nerves subserve these different manifestations of sensation in different degrees. The classification is a complete physiological one; it is almost certainly a complete anatomical one.

To subserve these different sensory functions the skin of the hand contains numerous end-organs in association with the terminals of the sensory nerves. These end-organs are of different types, and the special function, meaning, and connections of them all are by no means clear. Sensory nerves, upon approaching the surface of the skin, divide into a vast number of small terminal twigs which, ramifying in the subcutaneous tissue, compose the *deep cutaneous nerve plexus.* From this plexus fine filaments pass into the dermis, where they again become interlaced as the *superficial cutaneous plexus,* and from this plexus the nerve terminals pass on into the epidermis. In each of these situations specialised end-organs occur. All these end-organs are of comparatively complex structure, and most of them are named after their original describer.

In the epidermis the finest terminals of the nerves end in spaces between the epithelial cells (Retzius), or they may join into a fine meshwork and apparently terminate in the cells themselves (Langerhans). They may terminate as more definite end-organs, such as the intra-epithelial baskets (" paniers ") of Dogiel or the ivy tendril expansions (" expansions hederiformes ") described by Ruffini.

In the dermis the terminations of sensory nerves are extremely numerous, and again some appear to end as free filaments, which have been described by numerous observers, and others are in association with definite end-organs usually termed corpuscles. The best known of these are the corpuscles of Meissner, originally described by Wagner and Meissner in 1852, and to which are added as more recent refinements the varieties known as the corpuscles of Timoffew, the corpuscles of Dogiel, and the plexiform whorls associated with corpuscles described by Ruffini.

In the deeper layers of the dermis and in the subcutaneous

tissue occur the large and well-known bodies described first by Abraham Vater in 1741, and later by Filippino Pacini in 1840. These are usually known as the Pacinian bodies, or corpuscles of Vater-Pacini. Several other types have been described by later histologists. Of these the end-organs described by Gogli in 1880, and by Mazzoni in 1891, and the corpuscles, or terminal cylinders, of Ruffini (1891), are the most distinct in character and the best known.

Now, naturally, none of these end-organs are the exclusive property of the hand, for they occur in other portions of the skin and on other parts of the body, and in their distribution it is possible that some clue may be found as to their different functions.

The intra-epithelial nerve terminations were first described by Langerhans in the skin of the palmar surface of the terminal phalanges of the fingers, but they also exist in other sites. The ivy tendril terminations and the basket end-organs are said to be peculiar to mammals (Prenant and Bouin), and they are usually associated with the sweat ducts; they are therefore abundant upon the palmar surfaces of the fingers, but occur in other sites where sweat ducts are numerous. These three types of epidermal nerve terminals have been assumed (Ruffini) to subserve the function of transmitting the lightest touch applied to the surface of the skin, and therefore to be the end-organs of epicritic sensibility. Such an hypothesis is a very natural one when we consider their anatomical site, and it might be added that one would not expect the special receptive epicritic terminals to be at all conspicuous in the skin of the palm of the hand when that skin is contrasted with other areas of the body. In epicritic sensibility the old fifth nerve tactile area of the snout is far in advance of the palm of the hand.

The dermal end-organs, of which Meissner's corpuscles are the type, are those to which the name *tactile corpuscles* or *touch bodies* is almost universally given. These bodies are said to occur only in Man and monkeys, having never been found in animals lower in the scale (Schafer); they are, however, akin to structures described from the muzzle region of lower animals. It is in the palm of the hand, and also on the sole of the foot, that

these corpuscles are found in their greater numbers. "It has been calculated that the palmar surface of the tip of the fore-finger contains about 100 touch corpuscles for each two square millimetres, that of the second joint 40, and that of the third joint 15 in a like area. They are also found, though somewhat less plentifully, on the sole of the foot and toes, about 30 being present in two square millimetres of the last joint of the great toe, and 7 or 8 in the like area of the middle of the sole. They occur in the nipple of the breast, on the under, volar, surface of the forearm, being here, however, exceedingly scanty, at the edge of the eyelids and lips, and on the genital organs. From the greater part of the surface of the body they appear to be wholly absent" (Sir Michael Foster, "Text-book of Physiology," Book III., Chap. VI., p. 1409). It is worth recording that in the Spider Monkeys (*Ateles*) these corpuscles are abundant upon that ventral portion of the tip of the prehensile tail the likeness of which both in structure and function to the skin of the palmar surface of a finger we have already noticed.

The site of the subcutaneous Pacinian bodies is far more familiar to the medical student, since they are the only nerve terminals sufficiently large to be seen in the ordinary process of dissection. Their distribution is very remarkable. They are abundant upon the nerve terminals of the palmar surface of the digits, and upon the median nerve branches to a single digit there may be as many as 100 of these bodies clustered. By Rauber it has been estimated that, out of some 2,000 Pacini corpuscles found in the total skin covering of the body, some 828 are present in the fingers. Upon the soles of the feet he estimated 550, on the arm and forearm 322, on the legs and thighs 176, on the shoulders 24, on the buttocks 10, whilst 92 more are scattered upon the rest of the trunk. They are generally absent upon the backs of the hands and feet, and they are rare, if not absent, beneath the skin of the neck (Foster). But, curiously enough, these bodies are not confined to the subcutaneous tissue. They are found in deeper situations in connection with the nerves to the external genitalia and the mammary gland. They occur upon the nerves to the periosteum clothing the bones, and upon those supplying interosseous membranes, joint capsules, and tendons. They exist in

large numbers upon the thoracic and abdominal viscera in association with the plexuses of the sympathetic nerves, and they are also found upon the peritoneum and the pleura, and within the mesentery where sympathetic filaments terminate.

The corpuscles of Ruffini and Golgi-Mazzoni were both originally described from the palmar skin of the terminal phalanges of the digits, but by later observers they have been discovered in other situations (Dogiel). Whatever the functions of these larger and more deep-seated end-organs may be, it is obvious that they cannot be agents for appreciating " touch " in the ordinary sense of the word. From their association with the nerves supplying joints they have been supposed to be connected with the appreciation of position in space. They have been said to be the terminals of vaso-motor nerves, or to be connected with sensations of pain. They have been assumed to be associated with the sense of pressure, and more recently to be concerned in that extraordinary complex which manifests itself in certain nerve injuries, and is named causalgia. We know that in the hollow cavities of the body these end-organs are associated with the sympathetic nerves, and it has been suggested, and not without reason, that even those which cluster on the digital branches of the median nerve may in reality be associated with sympathetic nerve terminals.

In dealing with the hand from the point of view of its sensory representation in the cortex, we will therefore keep in mind the fact that it is an extremely important part of the " external nervous system " ; that the muzzle region, or in human anatomy the face, the palm of the hand, and in lesser degree the sole of the foot, are our tactile sense organs. In Man the hand has taken first place as a source of information about the environment, and it will therefore need a very wide cortical representation. The author does not deem it unduly fanciful to urge the recognition of the muzzle region and the palm of the hand as being not only sense organs which convey to the cortex a knowledge of the environment, but also as portions of the external nervous system which convey to the environment certain information about the " internal nervous system."

CHAPTER XXIV.

The Sensory Pathways.

In following the nervous pathway from the Rolandic cortex to the voluntary muscle we had a comparatively simple route to travel. First, we dealt with a path consisting of only two neurons. Then, in treating of movement, we are faced with a relatively circumscribed psychical condition, for we have imagined that the initiating stimulus may be regarded as a volition to alter the position in space of a part of the body, the projection of which in space is definitely known to us. This comparatively simple psychical act is modified only in so far as the " private path " influences of the cerebellum, the vestibular system, and the corpus striatum are brought to bear upon the lower motor neuron.

But in treating of the nervous pathway from the various sensory end-organs to the so-called sensory area of the cortex we are dealing with an exceedingly complex route. First, in the sensory pathway there is an added link, for, no matter what sensation we are attempting to follow, we have to deal with three separate neurons instead of two. Then again, " sensation," when we apply this word to the sensory activities of the hand, connotes an assemblage of separate qualities of which we have already made mention in the previous chapter.

The lowest sensory axon of any sensory nerve consists of a ganglion cell lodged in the posterior root ganglion from which one branch of the neuraxon passes by the posterior root to the spinal cord, and the other branch travels with the lower motor neuraxon through the limb plexus and along the peripheral nerves of the limb. These lowest sensory neuraxons, which run in the " sensory " and " mixed," as well as in the so-called " motor " nerves of the limb, terminate in the various sensory endings in muscles, joints, tendons, membranes, and in the subcutaneous tissue and skin.

But, as we have seen, these lowest sensory neuraxons and their end-organs subserve very different sensory impressions. They subserve superficial sensibility and deep sensibility, each of which is itself a compound. Superficial sensibility may be of the special nature of touch, pain, heat or cold, and it may be either protopathic or epicritic, or it may be concerned with the appreciation of separated stimuli and the precise localisation of these stimuli. Deep sensibility may be either the appreciation of pressure, of vibration, or of position in space. And the ability to recognise the form and nature of objects, or stereognostic sense, is a combination of both deep and superficial stimuli. It is, of course, most probable that some of these differences of special function are subserved by the different types of sensory end-organs, and it is also probable that the specialisation of different sensory neuraxons for the conveyance of specialised stimuli is accompanied by an underlying anatomical differentiation. Be this as it may, the study of injuries of peripheral nerves makes it clear that protopathic and epicritic, deep and superficial, sensory factors may be affected individually or in combination, and that different peripheral nerves contain the different factors in varying proportions.

From the sensory end-organs of the hand these impressions are streaming *viâ* the lowest sensory neuraxons carried in the median, ulnar, musculo-spiral and musculo-cutaneous nerves. As constituents of these nerves they pass into the brachial plexus, and emerge again upon the central side in the trunks of the mixed 5th, 6th, 7th and 8th cervical and first dorsal nerves. From the mixed trunk of the nerve they pass into the posterior or sensory root of the nerve, and in the ganglion of the posterior root they join the body of their parent nerve cell. Upon the central side another neuraxon of the posterior root ganglion cell passes from the posterior root-ganglion into the substance of the cord along the posterior root. In the posterior root these centrally running neuraxons are not all of one size, but are divided into fine and coarse fibres which remain congregated into more or less definite bundles. Upon reaching the spinal cord the fine fibres, for the most part, run to the side of the cord, while the coarse fibres run towards its posterior aspect.

Within the cord the lowest sensory neuraxon ends by coming into relation with a nerve cell of the grey matter of the posterior horn of the cord. Not only does the incoming sensory fibre come into connection with posterior horn cells, but by collaterals it effects a junction with the lower motor neuron cells of the anterior horn. These collaterals constitute the shortest path between incoming sensory stimuli and outgoing motor impulses, and they complete that path for reflexes which, so elaborated in lower animals, is comparatively insignificant in Man. Reflexes are essentially a protective mechanism in Man, although, as we have seen, the cell grouping within the cord may be so complex in some lower animals that highly co-ordinated movements may be carried out in a reflex manner by the agency of the spinal cord alone.

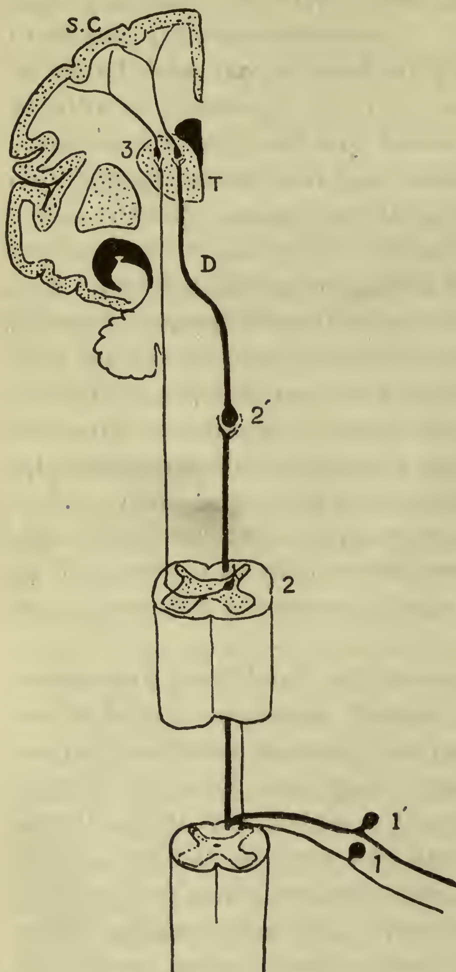

Fig. 110. — Diagram of the sensory paths. S.C. = Sensory cortex. T = Thalamus. D = Decussation. 1, 2 and 3 = Cell stations on the course of tactile pathway. 1′, 2′ and 3 = Cell stations on the course of deep sensibility path.

Such is the lowest sensory neuraxon. It consists of a nerve cell of the posterior root ganglion with a centrally running neuraxon and a peripherally running neuraxon, the first forming a constituent of the posterior root of a spinal nerve, and the second being bound up in a peripheral nerve. The fate of the centrally running neuraxons within the spinal

cord varies. Only this they have in common, that they end as a synapsis around some cell in the grey matter of the cord, and so make connection with the second sensory neuraxon. The level at which the several constituents of the lowest sensory neuraxon end in the cord varies greatly; some end in their synapsis almost immediately on entering, while some run considerable journeys within the cord before they come to an end in the first synaptic junction with a cell of the grey matter of the cord.

Now the physiological principle that underlies all the complicated anatomical arrangements of the sensory neuraxons within the cord appears to be simple enough in its general outlines. The great end attained by all the comings and goings within the cord is a regrouping of the neuraxons, and a reclassification of the stimuli which they are carrying towards the brain. The peripheral sensory nerve contains a dual superficial system of epicritic and protopathic fibres, as well as a component of fibres of deep sensibility; and it can inform the central nervous system of sensations of touch, heat, cold, pain, etc. But the sensation of pain may be produced either by deep or superficial fibres, or by epicritic or protopathic nerves. In order to sort impressions travelling to the brain there must, therefore, be a readjustment of the myriad streaming stimuli of one definite kind carried by the lowest sensory axon in a variety of channels. It is this readjustment which is effected in the cord. In the cord the regrouping consists of an integration of all the stimuli of one kind, no matter what their source. All the fibres subserving pain, touch, heat and cold, no matter if their source be superficial or deep, epicritic or protopathic, are isolated into separate groups travelling upwards in the cord. The individuality of the lowest sensory neuron is lost when the second sensory neuron is reached, for "as soon as the first synaptic junction is passed, on the passage upwards of afferent impulses, the characteristic features of protopathic and epicritic sensibility disappear" (Head, "Brain," Vol. XLI., Part II., p. 72, 1918). In following the pathways in the cord we are therefore dealing with qualities which are different from those in the peripheral nerves, for we are concerned with the course of fibres subserving sensations of pain, or touch, or heat and cold, and not those subserving deep

or superficial sensibility of a protopathic or an epicritic nature. It is, therefore, our business to trace the tracts in which pain fibres are lodged, and to distinguish these tracts from those carrying the fibres of touch and spatial recognition.

The terminals of the lowest sensory neuraxons, which convey impressions of *pain* and of *temperature*, travel the same route and pass into the posterior horn of the grey matter of the cord, here forming a synapsis about the nerve cell which is the parent of the second sensory neuraxon. This new neuraxon now passes across in the grey commissure to the opposite side of the spinal cord and runs upwards towards the brain in the lateral white column of the cord, forming a fibre in the ascending tract known as the spino-thalamic bundle. This tract runs from the cord and through the mid-brain as a leash of fibres known as the medial fillet, and here the fibres end in the basal grey nucleus, named the thalamus, by forming a synapsis around a ganglion cell in the thalamus from which the third or upper sensory neuraxon takes origin. The fibres of pain and temperature cross at varying levels in the cord; some of them run as lowest sensory neuron fibres for some distance in the posterior columns of their own side of the cord before forming their synapsis with the posterior horn cell and giving way to the second sensory neuron; and some end immediately upon entering the posterior horn of their own side. Ultimately, however, their fate is the same, for they find themselves as grouped and classified fibres of the second neuron in the lateral columns of the opposite side of the cord. The upper sensory neuron, which starts from a cell, in what may be termed the cortical portion of the thalamus, travels to the cortex of the brain, and there ends in the so-called sensory area of the cortex.

The course of the fibres subserving *touch* and *sensibility of contact* is rather more complex, and in general their combination and regrouping takes place at a higher level in the cord than is the case with the fibres of pain and temperature impressions. Upon entering the cord by the posterior root, some of the fibres of touch behave as do those of pain and temperature, and, after running in the posterior column of the same side for a short way, end in a synapsis around a posterior horn cell of that side. From

this cell the second sensory neuron of touch arises, and crosses the mid-line to the opposite side of the cord, as do those of pain and temperature, and takes up the rest of its course in the lateral column, whence it runs, *viâ* the fillet, to the thalamus, and establishes connection with the highest sensory neuron. But another, and apparently a larger, pathway is open to touch fibres, for the greater number of them on entering the cord run as lowest sensory neuron fibres in the posterior columns of their own side of the cord and give way to the second sensory neuron only when meeting a cell in the grey matter of the cord at the summit of the posterior columns. From this cell the second sensory neuron crosses the mid-line, and so goes to the upper neuron cell in the thalamus of the opposite side of the body. In dealing with touch fibres there are therefore two paths—the one which has a short lowest neuron, and a long second neuron, crossing the mid-line to the opposite lateral column, soon after entering the cord ; and the other characterised by a long lowest neuron, and a short second neuron, crossing to the opposite side of the body at the upper limits of the spinal cord. If one side of the cord is injured the patient will, therefore, be unable to appreciate painful and thermal impressions upon the opposite side of his body, but impressions of touch may be but little disturbed upon that side.

The fibres that for the present we will group together as those of *deep sensibility* run very much the same course in the spinal cord as do the late crossing fibres of touch and contact impressions. These fibres, upon entering the cord, remain uncrossed and ungrouped in the posterior columns of their own side, and they, with the temporarily uncrossed and unsorted fibres of pain, temperature and touch, constitute the two great fibre masses of the posterior columns known as the tracts of Goll and Burdach, or the funiculus gracilis and funiculus cuneatus. From these two columns the ungrouped pain and thermal fibres are constantly passing away to cross and become grouped as second neuron fibres in the lateral columns of the opposite side of the cord. The fibres of touch are also passing away, but, as we have seen, certain of them remain in the whole length of the posterior columns, uncrossed and ungrouped, as lowest neuron fibres in

the same way as the fibres of deep sensibility. The dual nature of the posterior columns does not denote any sensory specialisation in the fibres composing them, for it is an anatomical rather than a physiological grouping. The fibres streaming in by the posterior roots of the nerves supplying the legs take up their position in the posterior column at the lowest extremity of the cord, and as the great influx of posterior root fibres from the arm streams into the upper part of the cord it constitutes a lateral addition to the original tract of the posterior column. It is therefore true to say that the sensory fibres streaming in from the arm constitute the funiculus cuneatus, or column of Burdach, whereas those from the leg occupy the funiculus gracilis, or column of Goll. At the upper extremity of the spinal cord these two tracts swell out into two ganglionic masses, known as the nucleus cuneatus and nucleus gracilis, which produce prominences upon the dorsal surface of the medulla, known as the tuberculum cuneatum and the clava respectively. Within these ganglionic masses the lowest sensory neurons devoted to deep sensibility come to an end by establishing synaptic junctions with cells of the ganglia. From these cells the second sensory neuraxons arise and pass upwards in the fillet, and in the fillet cross the middle line by the sensory decussation in the mid-brain, and so pass to the thalamus of the opposite side of the body. From a cortical cell of the thalamus, in which the second sensory neuron ends, the upper neuron passes to the sensory area of the cerebral cortex. These long posterior column fibres, therefore, resemble the main motor tracts in that their crossing from one side to the other takes place high up in the central nervous axis.

Now, all the fibres with which we have dealt so far run from the cord to the thalamus of the opposite side of the body, thence making connection with the cerebral cortex; and they are therefore capable of carrying stimuli which will be able to force their way into consciousness. But a large proportion of the fibres of the posterior columns go, not to the thalamus, but to the cerebellum. This silent system of afferent impulses is one of the mechanisms which form the intermediaries between deep sensibility and movement, for it regulates and controls the poise of moving parts and co-ordinates the impulses connected with

muscle sense and the tone of muscles necessary to effect balance and posture.

Obviously the thalamus, by virtue of the great number of sensory fibres which stream by the fillet to its specialised cell layers, must be regarded as the great sensory receptor. The thalamus may be compared with the corpus striatum, the great basal submerged cortical mass which was at one time responsible for the initiation of movement. The thalamus, as the work of Elliot Smith has shown, is itself primitively cortical in origin, and these two bodies may therefore be regarded as respectively the sensory receptive, and the motor-initiating, mechanisms of the typical mammalian brain. But we have seen that in the case of the corpus striatum the function which it once possessed, and which it still possesses in lower animals, has been usurped by the cerebral cortex as far as all pictured movements are concerned. How, then, does the cerebral cortex stand in relation to the functions of the human thalamus? The recent work of Head upon cortical wounds inflicted in the war ("Brain," Vol. XLI., Part II., 1918), appears to put this question on a satisfactory basis. We have seen that if the so-called motor cortex is destroyed, we do not deprive the subject of movement; but we prohibit the performance of any movement of which the patient has an appreciation, as an actual picture of the part in relation to space. In the same way, when the so-called sensory cortex is destroyed, we do not deprive the patient of feeling or sensation, but we take from him all appreciation of discriminative relation of the part to space. A man who has suffered damage to the sensory area in the post-central gyrus of his cerebral cortex can feel pain, heat, cold and touch with the affected part, but he cannot appreciate its position in space, nor can he isolate or localise separate contacts made simultaneously. Again, he cannot judge of graduated contacts, so that he is unable to estimate weights placed upon the part or to realise the likeness or unlikeness of objects brought into contact with the part.

Obviously, most of the fibres involved in these forms of sensibility are those which are carried as long lowest sensory neuraxons in the posterior columns of the spinal cord, which we grouped together as fibres of deep sensibility, and to which are added

certain of the fibres subserving touch. It is probably justifiable to regard the columns of Goll and Burdach, and the nucleii gracilis and cuneatus, together with the crossed fibres of the fillet, as the great highway for the impulses of spacial appreciation and discrimination which are so essentially cortical in nature.

But the work of Head has demonstrated one thing which is far more important to us here, for he has shown how dominant in the cortical sensory area is the representation of the hand as an appreciative organ. It would appear to be rare to find any disturbance of sensation after a cortical injury in which the hand is not involved. But more than this, Head has shown that when the face is affected, the thumb and index finger will be likely to suffer too. This shows that the thumb and index are represented at the lower limits of the post-central convolution, a conclusion which we had already reached upon purely speculative grounds, for we have already pictured the thumb and index as being added next to the snout area in the phylogenetic building of the cortex. The little finger, again, is usually involved when a cortical lesion produces changes in the sensibility of the foot. We may therefore picture the sensory area of the post-central convolution as being largely occupied by the discriminative sensibility of the hand, arranged as a series of five individual digits, from pollex to minimus, as the area is followed upwards.

CHAPTER XXV.

The Nerves.

We are now in a position to appreciate the fact that the "nerves," as we encounter them in the body, are complex entities consisting of neuraxons of different kinds all bound together into a common trunk by a wrapping of fascia, which commonly contains fat, and which is known as the *epineurium.* Within this trunk are separate subdivisions, termed funiculi, each containing its own complement of neuraxons bound together by the *perineurium* which penetrates within the thickness of the trunk. Each funiculus is again permeated by finer derivatives of the same all-pervading fascial tissue which, under the name of *endoneurium,* envelops each neuraxon and its own proper coverings. These invasions of fascia are almost entirely supporting and protective in function, for the number of blood vessels which are carried by them to the neuraxons is extremely small, the neuraxon having, apparently, extremely little need for a vascular supply. It is this large proportion of supporting and protecting fascia which gives to the nerves, as displayed in the process of dissection, that great strength which is at first sight so astonishing. It also produces the very curious and puzzling condition by which some nerves appear to grow thicker the further they are traced towards their terminations. Every one who has had any experience of practical anatomy must have been struck with the minute size of the nerve roots as they emerge from the brain or the cord, and have subsequently been surprised at the large size of the nerve itself after it had travelled some way into the tissues of the body and given off a large portion of its neuraxons in its course. The further the nerve travels, and the fewer become its neuraxons, the greater is there need for the supporting wrappings of the fascia.

Within the thickness of the composite nerve the funiculi run a more or less independent course, and it is now possible in the case

of many nerves to determine with very fair accuracy the position of the different constituents in different portions of its course. That is to say, the motor fibres for one particular group of muscles occupy a fairly definite and independent pathway along the course of any mixed nerve. The information regarding these details of the intimate anatomy of the nerve trunks has been very largely gathered from the numerous cases in which partial sections of nerves have been caused by the passage of bullets in injuries studied during the War. But though the separate funiculi remain largely independent, the degree of what may be termed tangling of the nerve trunk varies greatly in different individual nerves. Thus, confining our attention to the nerves of the hand which concern us, the musculo-spiral nerve may easily be frayed out in the separate strands, and one particular strand (say the nerve supplying some individual muscle) may be dissected back along the trunk for a considerable distance; in the case of the median this is, at times, impossible, for in texture the median nerve is a tangle, whereas the musculo-spiral is a bundle of parallel strands.

Only three nerves need concern us in the study of the hand—the musculo-spiral, the ulnar, and the median.

The Musculo-Spiral Nerve.—Into the constitution of this nerve the 6th, 7th and 8th cervical nerves enter. It is one of the posterior or dorsal branches of the brachial plexus, being destined for the motor supply of the extensor muscles of elbow, wrist and fingers, and for the sensory supply of the extensor surface of the limb. In its sensory elements it displays a well-marked human peculiarity. The contribution from the 8th cervical root to the posterior nerves of the plexus is small, and, as a rule, the whole of the first dorsal nerve joins the anterior or ventral nerves by passing into the ulnar. There is, therefore, a deficiency in the segmental sensory supply to the back of the limb, and to compensate for this the ulnar nerve, which is itself an anterior or ventral nerve, supplies a large area of the back of the hand as well as the palmar surface which is its legitimate territory. There would seem to be little doubt that those ulnar fibres which supply the dorsum of the hand are trespassed fibres, which by rights belong to the musculo-spiral. It is to be noted

that in the gorilla, chimpanzee and gibbon the supply of the dorsum of the hand by the terminals of the musculo-spiral is very different from the condition typical of Man. In the gibbon the dorsal surfaces of the thumb, index, medius and half of annularis are supplied by the musculo-spiral branches as far forwards as the root of the nails.

Above the elbow the musculo-spiral divides into two branches, and these two branches are continued to the hand. At the division the motor and sensory elements become separated once again, for of the two terminals the posterior interosseous is practically entirely muscular and the radial is entirely sensory. The musculo-spiral trunk, and its posterior interosseous branch, supply between them the great extensor-supinator muscle mass of the upper limb. From the musculo-spiral itself branches run to the triceps and anconeus, which extend the elbow joint (7th and 8th cervical roots); and the supinator longus and extensor carpi radialis longior (6th and 7th cervical roots). The posterior interosseous sends muscular branches to the extensor carpi radialis brevior, the supinator brevis, extensor carpi ulnaris, extensor communis digitorum, extensor minimi digiti and extensor indicis, as well as the extensors of the thumb —the extensor pollicis longus, extensor pollicis brevis, and extensor ossis metacarpi pollicis. All of these muscles derive fibres from the 7th cervical root, and the 6th root supplies additional fibres to the supinator brevis and extensor carpi radialis brevior. The intranervous topography of these neuraxons in the musculo-spiral trunk appears to be fairly constant. The fibres for the supinator longus lie upon the lateral side of the nerve. To the inner border, and behind, are the neuraxons for the digital extensors, whilst laterally and behind are those for the extensors of the wrist. The sensory element, which comes off as the radial nerve, lies upon the front aspect of the parent musculo-spiral.

(*a*) *The posterior interrosseous* is a curious nerve, which runs but a short course as an entity, for its large muscular branches radiate so quickly from its trunk that its termination is by an extremely attenuated branch. It passes to the back of the arm through the substance of the supinator brevis, and before

entering this muscle it supplies it and the extensor carpi radialis brevior. On emerging from the supinator brevis its branches come off in two leashes. This separation into two is so definite that in most cases it would be necessary to describe the posterior interosseous as divided into two main portions at the lower border of the supinator brevis. The superficial portion comes to an end by breaking up into branches which sink into the extensor communis digitorum, extensor minimi digiti, and extensor carpi ulnaris; the extensor communis digitorum commonly being provided with two such branches. The deep portion supplies branches to the extensor ossis metacarpi pollicis, extensor pollicis brevis, and extensor pollicis longus; its last muscular branch sinks into the substance of the extensor indicis proprius. The deepest branch of the deep leash of nerves sinks beneath the tendons of the thumb extensors and passes on to the interosseous membrane and so to the back of the carpus. Here it becomes flattened and is finally lost as small branches which radiate over the posterior aspect of the capsule of the carpus, the joints of which they are said to supply. Such an ending is a curious one, and it would appear that the flattened portion of the nerve, which is sometimes incorrectly described as a gangliform enlargement, represents in a very rudimentary condition that cutaneous element which, as we have already seen, has passed to the ulnar nerve in the brachial plexus. In the gibbon, orang, and chimpanzee the nerve is continued over the carpus to supply the skin of the index and middle fingers.

As far as the hand is concerned the motor effects of injury to the musculo-spiral nerve are, therefore, paralysis of the supinators, of the extensors of the wrist, and of the extrinsic extensors of the digits. The classical symptom is the well-known "drop wrist." Inability to straighten the digits at the metacarpo-phalangeal joints follows paralysis of the extrinsic extensors, but it must be remembered that the terminal phalanges may be extended by means of the interossei. The thumb remains close to the rest of the digits, and cannot be pulled out of the way of the fingers as they close down in the attempt to make a firm grasp, an action which is already enfeebled by the

inability to raise the wrist and so give the flexors of the fingers their best opportunity for work.

(*b*) *The radial nerve* obtains most of its fibres from the 6th cervical, and is destined to distribute them to the skin over the

Fig. 111.—Loss of sensation on the hand after section of the musculo spiral nerve. Loss to all forms of sensibility is shown in the black area, loss to epicritic sensibility in the shaded area.

back of the radial side of the hand. It gains the back of the forearm some three inches above the wrist joint, and then divides into two branches, the one passing down to the thumb and the other dividing into four smaller branches which run to the thumb, both sides of index, adjacent sides of index and

medius, and cleft between medius and annularis. The branches on the thumb may be traced, by gross anatomical methods, to the root of the nail. Those on the index finger may be followed to the second phalanx, those on the medius only to the first phalanx, and the most ulnar-sided branch only to the root of annularis.

The curious feature concerning the cutaneous sensory supply of the hand by the radial is that, although its branches cover a fairly wide area of skin, it is from a sensory point of view an extremely unimportant nerve. It has even been stated (Sherren), and it has been widely accepted, that complete division of the radial nerve in the upper two-thirds of the forearm produces no loss of sensibility. This statement is not of universal application, for although the area of loss is very variable, it was only found to be absent in 2 out of 67 cases of complete division reported by Stopford.* When any disturbance of sensibility is present after the nerve is cut it manifests itself most obviously as the loss of appreciation of the very lightest touch of cotton wool. This epicritic loss may be confined to a small area upon the dorsum of the web between the thumb and index finger. It may be chiefly represented along the radial margin of the thumb, or it may extend over the dorsum of the hand so as to embrace the thumb to the root of the nail, and index and medius to the mid-point of their proximal phalanges. Protopathic sensation may suffer no loss at all after complete division of the radial, or there may be a small spot not so big as a threepenny piece situated between the thumb and the index finger where the prick of a needle, though not appreciated as pain, is recognised as touch. Deep sensibility, the perception of weight, and the appreciation of position in space remain unaltered over the area to which the terminals of the nerve are distributed, even when the nerve is totally severed. The loss of appreciation of heat and cold is usual over an area smaller in extent than that in which light touch sensations are lost.

The sensory supply of the radial nerve has become particularly well known in consequence of the classical experiment of Henry Head, who had his own nerve divided in 1903 in order to study

* *Journ Anat.*, Vol. LIII., pp. 14—25, October, 1918.

the effects of nerve regeneration.* It must be owned that the result of this experiment, and of the very large number of similar ones performed by bullets during the War, is extremely curious. We have seen that the nerve is tending to become of less importance in Man when comparison is made with the anthropoid apes and with lower animals, and possibly this phylogenetic recession accounts for the variability of the sensory importance of the human nerve. We may say that the radial supplies a variable area which may extend over the dorsum of the thumb, the web between thumb and index, and the dorsum of index and medius. This area it supplies with epicritic sensibility, but, probably by the overlap of neighbouring nerves, this area often becomes much diminished. The absolute area of protopathic sensibility is extremely small when tested by the point of a sharp needle, but section of the nerve leads to a loss of appreciation of heat and cold. Deep sensibility, on the other hand, appears to be in no way subserved by this nerve. Most probably the deficiency of sensibility in the radial area is made good to a large extent by the terminal branches of the musculo-cutaneous nerve which accompanies the terminal branches of the radial artery.

The Ulnar nerve is a mixed nerve, containing motor fibres for certain of the flexor muscles of the wrist and fingers, and for many of the intrinsic muscles of the hand, as well as serving as a sensory nerve for the ulnar side of the hand. It is one of the anterior or ventral nerves of the limb, although, as we have seen, it carries certain posterior or dorsal sensory fibres, which it appears to have robbed from the musculo-spiral. It is derived from the caudal end of the outflow of the fore-limb nerves, and only the 8th cervical and 1st dorsal nerves enter into its composition. Coursing from the brachial plexus down the arm, it comes to lie upon the back of the internal condyle of the humerus. It is in this site that stimulation of it by a slight blow produces the well-known feeling of hitting the "funny bone," and it is often said that it is owing to its superficial position here that nurses test the temperature of a baby's bath by dipping the elbow into it. From what we have seen of the

* See "A Human Experiment in Nerve Division, Brain," 1908.

facts concerning the appreciation of sensory stimuli, we should consider this last explanation extremely unlikely to be correct. The ulnar nerve enters the forearm by passing between the two heads of origin of the flexor carpi ulnaris, to which muscle it supplies two branches, containing motor neuraxons, just below the level of the elbow. The next motor branches are usually two which are given off to the two ulnar-sided slips of the flexor digitorum profundus about two inches below the elbow joint. No further motor neuraxons leave the mixed nerve trunk until it has passed over the anterior annular ligament and entered the palm of the hand. In the palm it divides into two main branches —a superficial branch, which contains motor neuraxons only for the palmaris brevis, and a deep branch, which is composed exclusively of motor neuraxons and supplies an important series of the intrinsic muscles of the hand. This branch passes between the abductor and the flexor brevis minimi digiti and supplies branches to both muscles ; it also supplies the opponens minimi digiti, and passing towards the radial side of the hand upon the palmar surface of the metacarpal bones, it supplies motor branches to all the interossei and the two ulnar-sided lumbricals. The nerve comes to an end by its terminal motor neuraxons sinking into the adductor pollicis, and the " inner head " of the flexor brevis pollicis. The motor effects of injury to this nerve will therefore be conspicuous. Flexion of the wrist can, of course, still be efficiently produced by other muscles in the absence of the action of the flexor carpi ulnaris, but the loss of its action as a muscle which pulls the whole hand in an ulnar direction is expressed by a tendency to radial deviation of the hand. The loss of power of the interossei prevents the fingers being spread apart and drawn together, except in so far as this action can be performed by the long extensors and flexors, as we have already noted. Loss of interosseus action on extension of the terminal joints is often compensated quite well by the long extensors, except in the case of the little finger. Loss of the flexion action of the interossei and lumbricals upon the meta-carpo-phalangeal joints is most marked, naturally, in the case of annularis and minimus, where both muscles are involved. The resultant deformity is a curious position taken up by the little

and ring fingers which gives rise to the characteristic main en griffe or claw hand. This clawing is produced because, in the case of the two postaxial digits, the lumbricals and interossei are both paralysed, and the extensor communis pulls the meta-

Fig. 112.—The distribution of the ulnar nerve in the palm of the hand. The nerves beset with Pacinian bodies are sensory branches, the shaded branches are motor.

carpo-phalangeal joints into a position of hyper-extension. In the case of the little finger the position is exaggerated, since four muscles—the flexor brevis, abductor, interosseus, and lumbrical —which produce flexion of this joint, are paralysed, and two muscles—the common and the proper extensors—can pull the first phalanx backwards. This hyper-extension of the meta-

carpo-phalangeal joints leads to a passive flexion of the two terminal joints, which cannot be straightened back by the paralysed interossei. If the nerve is divided high up, and the flexor profundus to medius and annularis is paralysed, the deformity is not so great as it is if the division is a low one, and this muscle is free to produce a further unopposed flexion of the fingers. There therefore results that curious fact that as the nerve begins to recover in a high lesion, and the flexor profundus comes into action, the deformity and uselessness of the hand increases. In addition to the clawing, the little finger is always drawn aside from annularis by the action of its proper and common long extensors. It therefore takes up very much the position in which this digit is held by some persons when drinking from a teacup. Clawing of medius and index is never at all well marked as the lumbricals to these digits are preserved, and therefore flexion of the metacarpo-phalangeal joints is still possible. Absence of the adductor of the thumb leads to all grasping actions between thumb and index being performed by a very characteristic pinching movement of flexion of the terminal phalanx of the thumb effected by the flexor pollicis longus.

The interneural topography of the ulnar appears to be more variable than is the case with most large trunks. The sensory portion generally appears to lie upon the anterior aspect of the trunk, and the motor neuraxons for the interossei and other intrinsic hand muscles upon the posterior and medial aspect, whilst upon the lateral side lie the neuraxons for the deep flexor of the two ulnar-sided digits.

Unlike the musculo-spiral, the ulnar nerve subserves all kinds of sensibility, for after its section protopathic and epicritic sensibility are lost as well as deep pressure and sense of position in its area of supply. The sensory fibres to the hand are distributed by three main branches: (1) the palmar branch, (2) the dorsal branch, both of which are given off in the forearm; and (3) the superficial terminal branch arising in the palm of the hand. The palmar branch is small, it accompanies the ulnar artery, and frequently joins with a neighbouring twig from the median. The dorsal cutaneous nerve is a large branch which

leaves the main trunk about three inches above the wrist and divides into branches which run to the ulnar side of minimus, the adjacent sides of minimus and annularis, the adjacent sides of annularis and medius, and to the dorsum of the hand towards

Fig. 113.—Loss of sensation in the palm of the hand after section of the ulnar nerve. Black = Total loss. Shaded area = epicritic loss.

the root of index. On minimus the nerves run as far as the root of the nail, but on annularis they go only to the second phalanx. The superficial terminal branch sends branches to the ulnar side of the hand, a branch to the ulnar side of minimus, and one to the adjacent sides of minimus and annularis. The dorsal digital branches and the palmar digital branches communicate with

each other, and on the borders of the ulnar area communications are made with the terminals of the radial and the median.

The area of ulnar epicritic sensibility in the hand varies somewhat, but as a rule it comprises the ulnar side of the palm

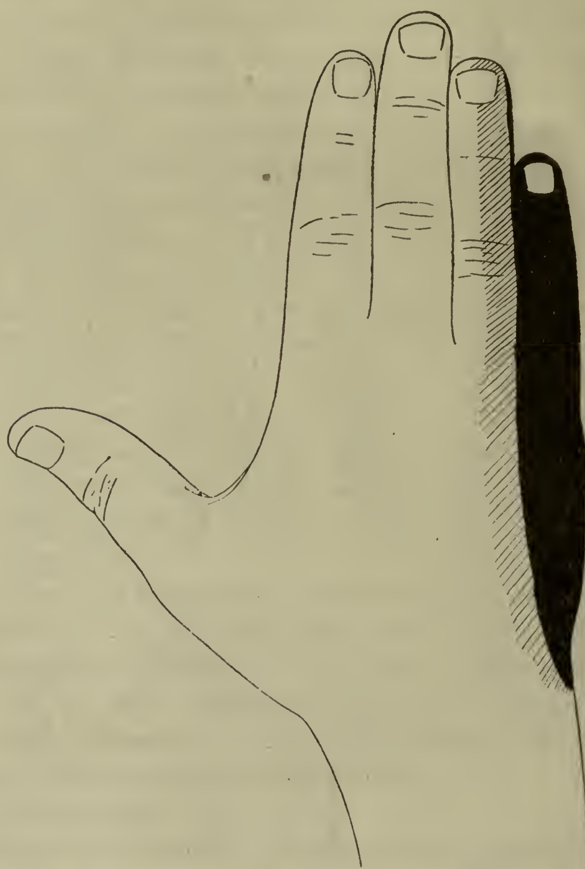

FIG. 114.—Loss of sensation on the back of the hand after section of the ulnar nerve. Black = total loss. Shaded area = epicritic loss.

of the hand as far as the middle line of annularis, the whole of the little finger, and the ulnar side of annularis; upon the dorsum the typical distribution of epicritic sensibility is almost exactly the same. Protopathic loss is complete in the whole of the little finger and a corresponding strip of the palmar and dorsal aspects of the ulnar side of the hand. A narrow strip of

protopathic loss also exists upon the side of annularis which is next to minimus. Deep pressure sensibility and sense of position are entirely lost in the little finger.

The ulnar nerve is therefore an important nerve in the hand. Its injury leads to a disabling deformity of the digits, to a loss of valuable muscular action, and to an important loss of protopathic sensation. Moreover, the muscles innervated by the ulnar nerve are used especially in producing fine movements, and they are highly educated muscles, the recovery of which is always more difficult than is the case in muscles which produce crude movement.

The *Median nerve* outweighs all the other nerves of the hand in importance. It is composed of fibres coming from the 6th, 7th and 8th cervical roots, as well as from the 1st dorsal. These fibres reach it by two definite strands known as its two heads of origin, the 6th and 7th cervical nerves enter by the outer head, and the 8th cervical and 1st dorsal by the inner head. The nerve is a mixed one, subserving all forms of sensibility and supplying motor neuraxons to the pronator-flexor group of muscles. Its first motor neuraxons are given off above the elbow joint to the pronator radii teres; immediately below more fibres pass to the flexor carpi radialis, and a second outflow to the pronator radii teres. All these fibres are derived from the 6th cervical segment through the outer head. Next, motor neuraxons from the 7th and 8th cervical and 1st dorsal, derived from both heads of the nerve, are given off to the flexor digitorum sublimis and to the palmaris longus. A second set of fibres to the flexor digitorum sublimis passes to the radial side of the muscle, and a third set given off low down in the forearm supplies the distinctive deep portion of the muscle destined for the index finger. A little distance below the elbow a deeper set of fibres leaves the nerve, and branches supply the flexor pollicis longus and the radial portion of flexor digitorum profundus, the deep portion being continued downwards on the interosseous membrane as the *anterior interosseous nerve*, which ends as one branch which passes to the deep surface of the pronator quadratus, supplying it with motor neuraxons, and another continued on the front of the interosseous membrane

to the palmar surface of the wrist joint. The deep portion of the nerve contains fibres, coming through both heads, derived from the 7th and 8th cervical and 1st dorsal roots.

The main trunk of the median enters the palm of the hand by passing deep to the anterior annular ligament. In the palm of the hand it gives off motor neuraxons to the abductor pollicis, the opponens, the outer head of the flexor pollicis brevis, and to the two radial-sided lumbricals. In English text-books it is usually stated that the neuraxons for the median intrinsic muscles of the hand are derived from the 6th cervical segment, and in French works the 7th cervical is commonly given as their source. But stimulation of the two heads of the nerve as they are exposed on the operating table shows that most commonly the source of these neuraxons is derived *viâ* the inner head of the nerve. In some cases stimulation of the outer head will produce movements of the thumb, but these cases are in the minority. Evidently, therefore, the intrinsic muscles of the thumb are often innervated by a lower root than that usually given.

We may therefore say that the main pronator and the wrist flexors are innervated *viâ* the outer head of the nerve, the long flexors of the digits obtain motor neuraxons through both heads, and the intrinsic muscles, as a rule (but not invariably), by way of the inner head.

The intraneural topography of the median nerve appears to be a good deal confused, and this we might expect, since we have already noted that it is, in the greater part of its length, typically a nerve of tangled texture. The motor neuraxons for the flexors appear to be upon the posterior and medial surface, and those for the pronator upon the anterior and external surface. The fibres for the thumb muscles are situated at the posterior aspect of the main nerve.

The sensory fibres of the median which are concerned in the supply of the skin of the hand come off from the main nerve as several named branches. First is the palmar cutaneous branch, which arises in the forearm and ends in the skin of the palm of the hand. Then, from the main nerve when it has entered the palm of the hand, five digital cutaneous branches are given off.

The first and second digital nerves run along the two margins of the thumb, the third courses up the radial side of index, the fourth supplies the adjacent sides of index and medius, and the fifth goes to the adjacent sides of medius and annularis and communicates with the digital branch of the ulnar.

FIG. 115.—The distribution of the median nerve in the palm of the hand. The nerves beset with Pacinian bodies are sensory branches. The shaded branches are motor.

Apart from these anatomical sensory and motor branches, which have a very general similarity to those previously described in the case of the ulnar, the median nerve presents several very striking peculiarities. In the first place it gives off a great number of branches which go to bones, to joints, ligaments and

interosseous membranes. It gives off a striking number of branches to blood-vessels; in fact, it might almost be said to have the monopoly of the neuro-vascular supply of the fore limb. Then, again, its terminal branches are characteristically beset with those end-organs which we have previously mentioned as Pacinian bodies. Moreover, the median nerve in naked eye appearance is strikingly different from any other nerve in the fore limb. As it passes into the palm of the hand it swells out into an almost gangliform enlargement, which has the peculiarity of being pinkish grey in colour, and is very unlike the yellowish white which is typical of most other nerves. The living median nerve has this peculiarity of appearance, and in this detail it is matched only by the distal portion of the internal popliteal as that nerve turns into the sole of the foot. Then, too, the median nerve has in its midst an artery—the arteria comes nervi mediani—a detail in which again it finds its likeness in the internal popliteal nerve.

The median nerve supplies with epicritic sensibility the palmar aspect of the thumb, index, medius and radial half of annularis, and the corresponding portion of the palm of the hand. On the dorsum epicritic fibres supply index, medius and half annularis over their two terminal phalanges. Protopathic loss in section of the median is present on the palmar and dorsal surfaces of the two terminal phalanges of index and medius as well as a varying extension on to the palm of the hand. Over the same area deep sensibility, sense of position, and all other forms of sensation are utterly lost. Moreover, in addition to this, there results a curious disturbance of the well-being of the tissues. The fingers are glossy and red, or in cold weather blue, their texture is pulpy, their nails ill-formed; and various other disturbances—commonly termed trophic—are produced.

The median nerve is therefore a curious and highly important one, for though the motor loss in complete division may be comparatively little, the sensory and trophic disturbances are always very severe. There is no nerve in which reliance on text-book knowledge would lead one to expect more, and actual examination reveals less, motor loss than in the case of the median.

Without entering into details which are too strictly clinical, one fallacy in testing the voluntary power of muscles may here appropriately be pointed out. The median nerve supplies the whole of the flexor digitorum sublimis and the radial side of the

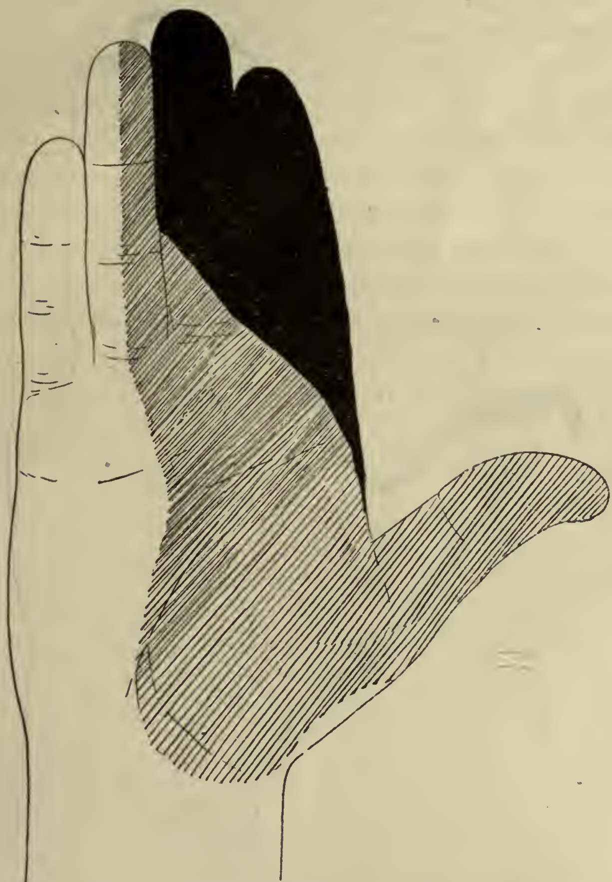

Fig. 116.—Loss of sensation on the palm of the hand after section of the median nerve. Black = Total loss. Shaded area = Epicritic loss.

flexor profundus. We might therefore imagine that after division of the nerve the patient would not be able to flex the first interphalangeal joint of any finger, nor the terminal interphalangeal joint of index or medius. As a matter of fact, if the patient is asked to make a fist, it will sometimes be evident that he can bend all the joints of all the fingers. The flexor

profundus can flex the first interphalangeal joints after it has flexed the terminal joints, and so " wind up " the fingers and close them into the palm. But even allowing for this, the index and medius should be completely paralysed, since both super-

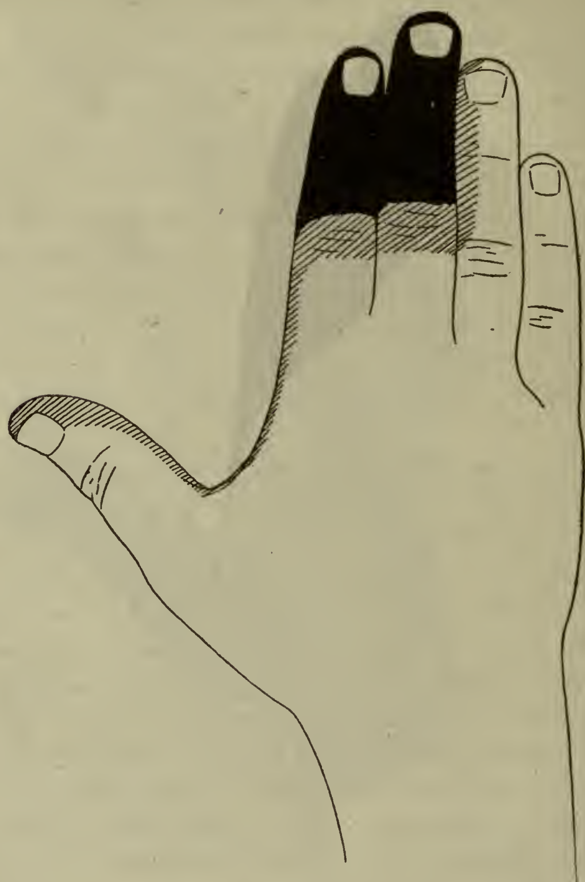

FIG. 117.—Loss of sensation on the back of the hand after section of the median nerve. Black = total loss. Shaded area = Epicritic loss.

ficial and deep flexors are affected, and yet they too bend, though certainly not so far as annularis and minimus. Now, when we ask a patient to perform an action, we ask his cortex to produce a volition for movement—and we are apt to forget that the cortex knows only of movements and nothing of muscles. If the patient, therefore, desires to close his hand into a fist,

any muscle which can help will be called into action. The flexor profundus is, in part, supplied by the ulnar nerve, and apparently, when the volition is a general one, the contraction of the ulnar portion is sufficient to produce a pull on the radial-sided tendons and cause an incomplete movement in index and medius. It is only by isolating the index finger, and getting the patient to centre his attention on bending its terminal joint, that the paralysis of the flexor profundus in this digit becomes apparent. This observation applies to all cases of testing the voluntary power of muscles. The patient may be instructed to effect a movement, but this will not ensure his using a definite muscle unless that muscle—and that muscle only—can effect the movement. [For further details see "Muscular Movements in Cases of Nerve Injury," *Journal of Anatomy*, October, 1919.]

CHAPTER XXVI.

The Vascular Channels.

The study of the vascular mechanism of any part involves the examination of the arteries which bring the blood to the part, and of the veins and lymphatics which return the various elements of the blood to the chambers of the heart. In dealing with the hand we have to face those problems of peripheral circulation which are common to all parts of the human body, and we will enter into details only so far as is necessary to illustrate the general principles.

When we consider the vascular mechanism from the point of view of phylogeny, it at once becomes apparent that the separation of the veins and arteries from the lymphatics, which is so sharp-cut in the literature of the human circulation, is in reality only a question of physiological specialisation in a primitively single system.

The work of Huntington and McClure (see *Amer. Jour. Anat.*, Vol. XVI., Part III., 1914, for summary and literature) has made it clear that we have to deal with a phylogenetic elaboration of tissue spaces in which the circulating fluids of the body make their circuit. There are two great functions demanded of these circulating fluids. They have, firstly, to carry the mobile wandering tissue cells known as white corpuscles, and secondly the non-mobile oxygen-fixing bodies known as red corpuscles. Of these two duties, it is the first which is their most ancient physiological *rôle*.

A primitively simple vascular system may be considered to be one in which only white corpuscles and the fluid plasma move through the body in a series of tissue spaces. In the terms of human anatomy such a vascular system would be regarded as a primitive lymphatic system. Next, in phylogeny, a respiratory function is demanded of the circulating fluids, and oxygen-

carrying bodies are borne in its stream, as well as the more primitive agents of pure tissue nutrition.

Such a circulatory system is realised in the lowest vertebrates, and may be termed a lymphatico-hæmal circulation. Finally, progressive specialisation leads to such a separation of the hæmal and the lymphatic vascular systems that in adult anatomy they are apt to be treated as more or less independent entities ; and doubtless this customary severance of the two constituents of the vascular system in descriptive anatomy is usually carried too far.

The study of the development of the system in the embryo confirms the same conclusions, for, no matter what may be their adult condition, all the peripheral vessels are developed alike as tissue spaces, which afterwards become confluent, and form a connected system of channels. These channels ramify throughout the whole of the body, communicating freely among themselves, and, at a later stage, communicating with the central pulsatile organ of the circulatory system. The solid constituents of the blood are developed within the tissue spaces and, for a time, the contents of all the tissue spaces, no matter if they are destined to be arteries, veins or lymphatics, is the same. That is to say, those channels, which in the adult are known as lymphatics, contain in early embryonic life both red corpuscles and white corpuscles, or they have, in Huntington's words, a "hæmophoric stage." But when once the development of the circulatory system has reached such a stage that a definite motion is imparted to the fluids, a change comes about in the contents of those channels which are ultimately to be lymphatics. The contents move on towards the central pulsatile portion of the circulatory system, and red corpuscles and white corpuscles flow to the heart from both the venous and lymphatic channels alike. Both sets of corpuscles pass out again along the meshwork of tissue spaces destined to become the arteries. But though the red cells find their way back from the arterial meshwork to the venous meshwork, they are never able to negotiate the tissue spaces intervening between the arterial meshwork and the lymphatics. The mobile white corpuscles and the plasma may return by lymphatic channels, but the red corpuscles having

once passed to the heart never again find their way back to the lymphatics from the terminal ramifications of the arterial channels. The veins alone are able to admit all three elements of the blood by their ultimate radicles in tissue spaces. When once the early hæmophoric stage of the lymphatics is passed they cease to be blood-vessels in the strict sense of the term.

Lymph therefore flows centralwards in the lymphatics while blood flows centralwards in the veins, and in this way the two systems have become to a certain extent separate by specialisation. Nevertheless, the communication between veins and lymphatics is not by any means limited to the entrance of the thoracic duct into the veins of the left side of the root of the neck. The older anatomists believed that lymphatics communicated with veins in many places, and the more recent work of the American investigators has shown that their assumption was correct.

We will therefore regard the lymphatics as being part of an older circulatory system upon which the newer one has been grafted, and we will look upon it as differing from the venous system mainly in the fact that red corpuscles, which may make the tour from the arteries into the veins, are debarred from finding entrance into its terminal ramifications.

As we should imagine from the study of their origin in tissue spaces, all vascular channels are at first plexiform, and from the original plexus the adult channels weave themselves out as development proceeds. Such an origin prepares us for finding a far greater variation in the anatomical disposition of vascular channels than we have hitherto met with in the other constituents of the body. Some animals, as *Nycticebus* among the Lemurs, and some of the sloths preserve a plexiform arrangement of the limb arteries in the adult, and though obviously, in these cases, it is retained in response to the same functional demand, it is by no means easy to say what this demand may be.

In the arm this primitive arterial plexus is situated in the midst of the limb, and follows the course of the median nerve. In the adult condition this primitive channel has been considerably modified by the development of side branches, which dominate in importance the older central axis. The adult

axillary and brachial arteries represent the primitive arterial system as far as the elbow joint, but below the elbow joint the primitive channel is dwarfed by the development of two new arteries, the ulnar and the radial. The old plexiform channel

Fig. 118.—The median artery entering the hand and supplying the thumb and index finger.

persists as the anterior interosseous artery, which runs between the two bones of the forearm, and the arteria comes nervi mediani, or median artery, which adheres to its old course along the median nerve. In most cases the median artery is an inconsiderable channel which plays no part in the blood supply of the hand, but occasionally it persists in its primitive form as a

large vessel, and not uncommonly it makes a contribution to the arterial arcades in the palm of the hand from which the blood supply of the fingers is derived (see Figs. 118 and 119). In all cases the artery is probably important from a point of view which

FIG. 119.—The median artery entering the hand and joining with the ulnar to form the superficial palmar arch.

will be discussed later. The radial artery, in which the pulse is commonly felt, and the ulnar artery are both new channels, and the details of their course in the forearm need no especial mention here. In the palm of the hand they exhibit a common type of terminal arterial circulation in the formation of anastamotic arcades from which the ultimate arteries are given off.

Two such arcades commonly exist in varying degrees of completeness, and they are known as the superficial and deep palmar arches.

The superficial palmar arch, which lies superficial to the long flexor tendons, is derived mainly from the ulnar, and in the

FIG. 120.—Classical type of superficial palmar arch.

classical type the arch is completed by a small branch from the radial which is known as the arteria superficialis volæ (see Fig. 120). This branch of the radial may, however, be lacking, and then the arch is incomplete upon its radial side, or some other branch of the radial to the thumb or index finger, or the median or the interosseous artery may join the ulnar in the

palm. Usually four digital arteries arise from the superficial arch for the supply of the fingers. The deep arch lies upon the metacarpal bones and interosseous muscles, being deep to the other muscles of the hand. It is made up by the deep branch of the ulnar meeting the main trunk of the radial which has

Fig. 121.—Superficial palmar arch derived from the ulnar artery alone.

entered the palm from behind the thumb (see Fig. 122). As a rule, three interdigital branches arise from the arch and run to the interdigital clefts, there to join with the digital arteries of the superficial arch for the supply of the adjacent sides of the digits. The digital arteries derived in this fashion run with the digital nerves along the sides of the fingers supported by Cleland's

skin ligaments, and beneath the terminal pad of the fingers the arteries of either side of the digit enter into a complex terminal anastomosis. Besides the digital branches other arteries are given off from these two arterial arcades to all the muscles, joints, bones and other tissues of the hand.

The primitive veins of the limb are even more plexiform and tortuous in their course than are the primitive arteries, and at all times veins exhibit a higher degree of variation in their adult disposition than do the arteries. Although venous channels preserve a definite degree of physiological or functional uniformity in their main distribution, the anatomical disposition of their actual branches is subject to a very wide degree of variation.

Early in embryonic life the veins of the anterior extremity consist of preaxial and postaxial marginal plexuses which run along the superficial aspects of the two borders of the growing limb bud. Of these two marginal plexuses, the postaxial or ulnar-sided system is the largest and most important, and is also the phylogenetically oldest. This is the primitive ulnar vein which in the adult is represented by the veins of the ulnar border of the hand and forearm and by the brachial, axillary, and subclavian veins. The preaxial or radial-sided plexus has as its adult representative (even if its ontogentic history is not completely consecutive) in the veins of the radial side of the hand and forearm and the cephalic vein. In addition to these superficial marginal plexuses is the network of deeper venous channels which accompanies the arteries.

The adult superficial veins run between the skin and the deep fascia and form a series of blood channels which are larger than the deep veins in the hand, and which, though numerous upon the dorsal surface, are comparatively few upon the palmar surface. Upon the dorsum of the hand the veins start as a complicated meshwork of channels woven around the terminal phalanges. From this plexus the blood tends to collect into two veins which run along the two sides of the dorsum of each digit, the two dorsal veins being connected by numerous smaller cross channels at intervals on their passage to the bases of the proximal phalanges. At each interdigital cleft the superficial veins commonly effect a junction with the deep veins and, augmented

in size, run in a somewhat irregular manner across the dorsum

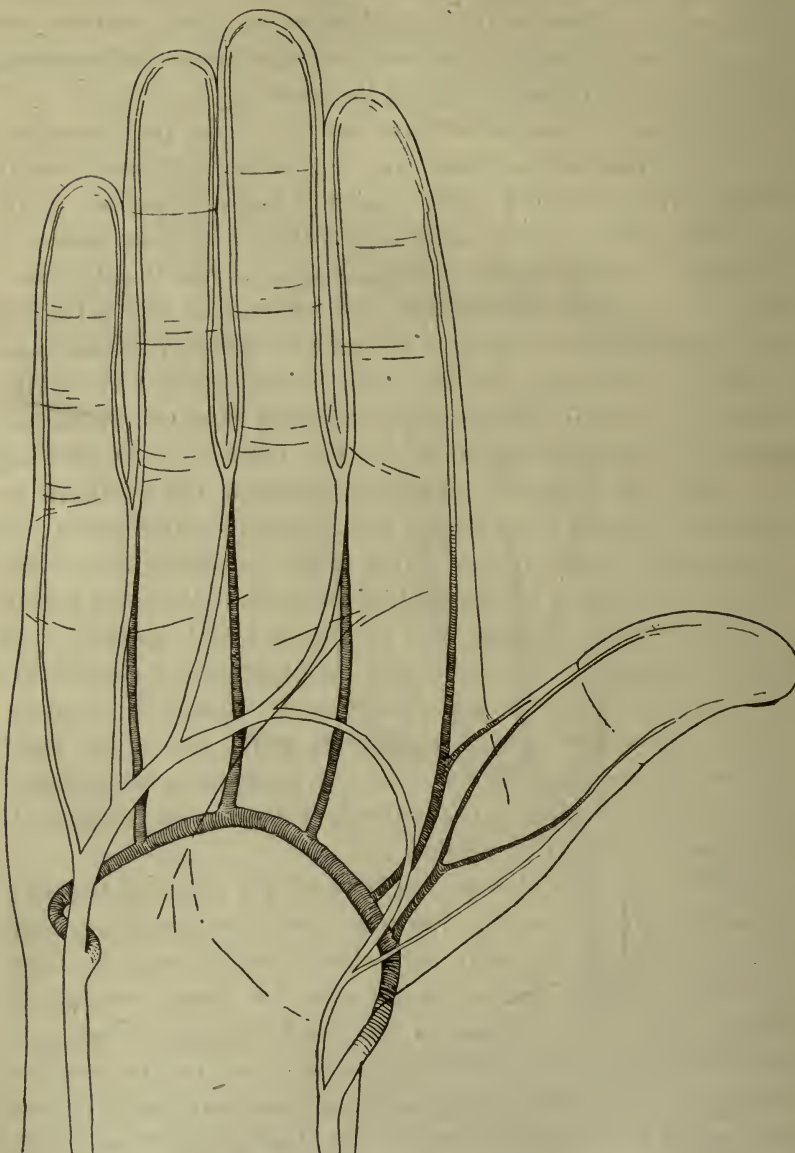

Fig. 122.—The deep and superficial palmar arches.

of the hand towards the wrist. As a rule, a large and distinct channel runs along the ulnar side of the dorsum of the hand from

the interdigital cleft between minimus and annularis. This is "that vein which the Arabians call Syele, we commonly Salvatella" (Helkiah Crooke, "Mikrokosmographia," p. 641, 1651). Concerning this vein there is a wealth of legend and blood-letting lore. "The section of this vein in the left hand is held by the Arabians and by many other Practitioners in physic to be of great avail in melancholy diseases." A belief in a particularly direct channel from the veins of the little finger of the left hand to the heart is one that has often been voiced in the dark ages of anatomy. As the vena salvatella runs upwards over the wrist in relation to the styloid process of the ulnar, it is joined by numerous irregular superficial branches and usually by deep branches near the wrist joint. Increased in size, it now becomes the ancient basilic vein, or, as it is more commonly known in modern anatomy, the ulnar vein—a venous channel which is commonly complex and compounded of at least two separate veins. This system runs up to the front of the elbow, where, joining deep veins in the bend of the elbow and increasing greatly in volume, it constitutes the trunk to which to-day we limit the term basilic vein. Like the vena salvatella, this is a vein of much distinction in the literature of phlebotomy. Its name denotes its great importance. Blood-letting from the basilic vein is a time-honoured procedure, and the blood-letting was no haphazard procedure, "for in the right arme it is called Hepatica or the liver-vein, because it is opened in diseases of the liver. In the left arme it is called Lienaria or spleen-vein, because it is opened in diseases of the spleen" (*Ibid.*, p. 642). The basilic runs upwards in the arm, and again makes communication with the deep veins by opening into the axillary vein.

Upon the radial side of the dorsum of the hand the blood is drained away from the dorsal plexus by a vein which also runs an irregular course, picking up numerous tributaries as it goes, to the flexor surface of the elbow. The whole length of this vein in hand, forearm, and arm was originally known by the name of vena cephalica, the vein on the dorsum of the hand being known as the vena cephalica pollicis, but in modern anatomy it is customary to name the part in the forearm the radial vein. The radial vein, like the ulnar vein, joins deep

veins at the bend of the elbow, and then runs upwards as a larger channel to join the axillary vein. Its termination in the veins of the axilla is a matter of considerable interest. In the human fœtus, and in the majority of mammals, its opening is

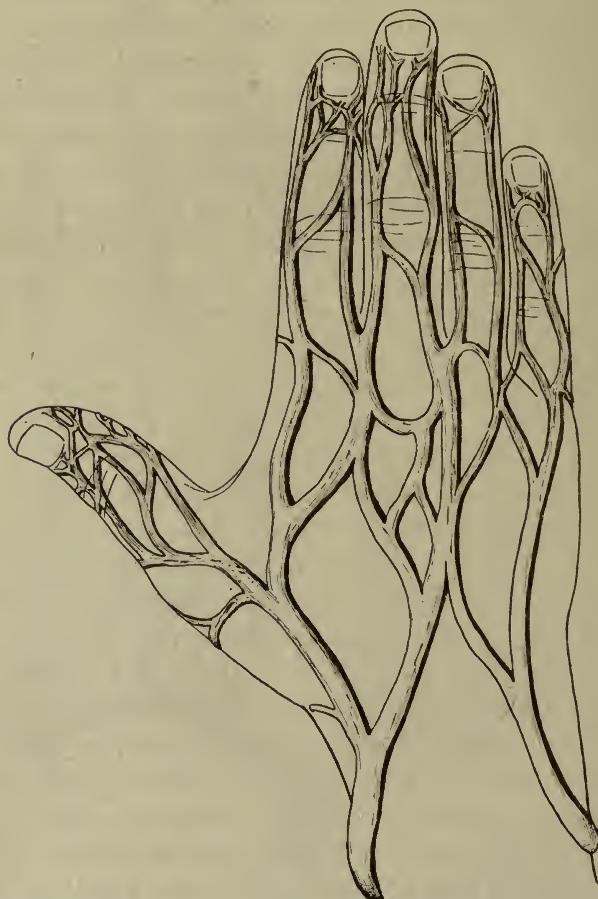

Fig. 123.—The arrangement of veins upon the dorsum of the hand.

made into the external jugular vein of the neck. This type of termination occasionally occurs in the human adult; but by the earlier anatomists, who gleaned their knowledge from the examination of lower animals, it was considered as the normal human disposition of this vein. For this reason "it is called Cephalica because it is wont to be divided or opened in diseases

of the head." It is probably the old belief in the specific effects of venesection of the several veins of the arm which has given us our present Greek nomenclature, and although we retain the term "cephalic vein," and justify it by reference to comparative anatomy, we have discarded the alternative term of vena ocularia for the same venous channel.

Upon the palmar surface of the hand there are but few superficial veins, and such as there are join together at the wrist to form the median vein. This vein behaves like the basilic and cephalic, for at the bend of the elbow it joins the deep median vein, and from the confluence of deep and superficial channels result the two junctional veins (termed median cephalic and median basilic), which we have noted as joining the cephalic and basilic veins respectively. In the forearm the median vein is commonly an inconsiderable channel, but at the bend of the elbow its junction with the deep vein produces a very large trunk which almost immediately divides into the branch to the basilic and the branch to the cephalic. This short trunk, which shows conspicuously beneath the thin skin of the bend of the elbow, is the "black vein" of the early anatomists.

The deep veins of the hand exist as numerous channels—named venæ comites—which are meshed around, and accompany the arterial arcades. In the palm of the hand these veins are extremely numerous, and every surgeon is aware of the free bleeding which accompanies the most trivial operations upon the structures of the palm. We have previously noted the likeness which exists between the texture and disposition of the fascias of the palm and of the scalp, and these circumstances result in a similar peculiarity of the venous channels. Scalp wounds bleed profusely, and so do wounds of the palm, and this is due in both cases to the density of the tissue with which the vessels are surrounded, and which prevents the retraction, contraction and closure of their cut ends. We will note here, and discuss later on, the fact that whereas the veins of the dorsum of the hand are mostly situated quite superficially, those of the palm of the hand are, for the most part, buried deep beneath the palmar fascia. The deep veins communicate at the bases of the fingers, and at the wrist, with the superficial veins, and are continued

up the forearm as venæ comites to the several arteries to the elbow joint. Here again, as we have previously noted, they effect a communication with the superficial veins. In the arm they are again combined as plexiform venæ comites to the brachial artery, and again they join the superficial veins and run as a more or less discrete trunk as the axillary vein.

Now in the hand, forearm, and arm there is exhibited a general principle which applies throughout the body—wherever veins run their course in the midst of muscle masses they always assume the form of plexiform, multiple, and incompletely valved channels. It is therefore misleading to describe such a venous channel as the brachial vein, for the brachial artery is surrounded by muscle masses, and, far from being accompanied by a discrete vein, it is, as a rule, surrounded by a maze of venous pathways which enmesh the artery and ramify upon every aspect of its walls. The surgeon who expects to cut down upon a brachial artery and a brachial vein will possibly be disconcerted by the number of veins from which hæmorrhage occurs and has to be controlled. On the other hand, wherever venous channels are free of muscular masses, they exist as discrete, single and valved vessels. The whole of this arrangement is a highly specialised adaptation for the purpose of securing the return of venous blood from the limbs. When muscles contract they squeeze the blood from the veins which lie in their midst, and press it onwards into the discrete and valved channel which emerges from their mass. Thus the muscles of the hand squeeze the blood onwards into the more or less discrete veins at the wrist. The muscles of the forearm squeeze it on to the discrete veins of the bend of the elbow, and the muscles of the arm finally press the blood in the brachial venæ comites into the valved axillary vein, and so to the subclavian and the heart. The muscular heart pumps the blood along the arteries to distal parts, and it is returned along the veins by the muscle pumps of the limbs. These limb pumps are arranged as a series of Higginson's syringes, each pressure area passing the blood through valved channels to the next pressure area. The system is further adapted for its physiological *rôle* by the anatomical arrangement of a superficial and a deep set of veins and those communications, which we have

noted, between the deep veins and the superficial channels in the intervals between the muscle masses. The superficial veins of the body are situated outside the ensheathing fascia of the muscles and so are shielded from the pressure which they produce by their contraction. More than this, they are disposed in such positions as to avoid external pressure. It is an old observation that the deep veins are numerous but the superficial veins few in the palm of the hand where pressure is so often exerted, whereas the reverse is the case on the dorsum. When prolonged contraction of the muscle masses takes place in long-sustained effort the deep veins are subjected to continuous pressure, and therefore an alternative route is provided by the superficial veins. This alternative route is offered at every interval between muscle masses, or, as a general rule, at every joint in a limb. The deep veins are protected from over-dilatation by the support of the muscle masses, and by the elastic stocking of deep fascia wrapping round these masses, but the superficial veins have no such support. We have previously noticed that in the position of rest of the limb the blood gravitates into the arm, fills the venous channels in the quiescent muscle masses, and, in a dependent part, engorges the superficial veins. With returning activity the muscle pumps of the limbs come into play and the return of blood from the limb is again accelerated. It is also to be noted that the opposite condition of long-continued muscular effort produces engorgement of the superficial veins by producing sustained pressure on the deep veins. It therefore happens that two entirely different conditions may lead to an extra burden of venous blood being borne by the superficial veins, and so, in the lower limb, producing that permanent dilatation known as varicose veins. How important is the muscle pump of the limbs in effecting venous return from the limbs may be gathered from a study of the modified fore limbs of the bats. In the wing membrane the veins are running in a field which is altogether free of muscle masses; no pressure can be exerted on them from without. In these circumstances there occurs that curious phenomenon, first noticed by Wharton Jones (*Phil. Trans.*, February 5th, 1852), of pulsatile veins. The veins of a bat's wing membrane

are pulsatile like arteries, and return the blood to the heart unaided by the limb muscle pump. Here is a case in which a specialised forearm begets the need for a special vascular mechanism unknown in other animals (see also Wood-Jones, *Lancet*, April 14th, 1917). The presence of valves in the veins of the forearm may easily be demonstrated by placing one finger over a vein upon the back of the hand and so preventing blood from flowing into it from the fingers. If whilst the ingress of the blood is there cut off the vein be emptied by running another finger along it towards the elbow, it will be found that it will remain empty for a certain interval, the blood being pushed up beyond a valve which prevents the vein refilling from above, while the pressing finger prevents the entry of blood from below.

The lymphatics, like the veins, are thin-walled, tortuous, and valved channels, but, since their contents are colourless, the details of the ramifications in the tissues are not so familiar to the student of anatomy as the consequences of their pathological changes are to the clinician. At intervals lymphatic vessels are in connection with lymphatic glands. Lymphatic glands are usually situated in what may be termed the quiet spots of the body. None are found in the hand, wrist or forearm until the elbow is reached, and then, as a rule, we encounter one gland, or sometimes two or even three, placed superficially over the internal epicondyle of the humerus. Large numbers of lymphatic glands are present in the axilla; others again, small in size and inconstant in number, are occasionally found in the intermuscular interval, between the pectoralis major and the deltoid, which lodges the cephalic vein. The next glands are situated above the clavicle at the root of the neck. In addition to these superficial glands, variable and small lymphatic nodes are at times found along the course of the arteries of the arm. As for the lymphatic vessels themselves, the general rule which prevails throughout the body—that superficial lymphatics accompany veins while deep lymphatics accompany arteries—holds good. Deep lymphatic vessels accompany all the arteries of the hand, forearm, and arm. Cutaneous lymphatics compose a maze of anastomotic channels which surround the finger, run

on the palmar and dorsal surfaces of the hand, and weave themselves out into numerous lymphatic pathways which follow the lines of the superficial veins. It therefore comes about that lymphatics from the ulnar side of the hand follow the course of the vena salvatella and the basilic vein, and so make connection with the glands of the internal condyle. Lymphatics from the palmar surface run with the median and cephalic veins to the axillary glands, and the bulk of the dorsal lymphatics follow the same course. But some channels do not end in the axillary vein, for they run in the intermuscular interval between the pectoralis major and the deltoid with the cephalic vein and, following the primitive course of this vessel, pass up into the neck, where they communicate with the lymphatic glands above the clavicle. The lymphatics which follow this course are mostly those derived from the dorsum of the thumb and index finger, and although it is said that there is no real scientific basis for the old-established belief that wounds of this area are liable to be followed by grave consequences, it is certainly true that the lymphatics from this dreaded portion of the hand run a longer course free of the intervention of lymphatic glands than any other vessels in the fore limb.

CHAPTER XXVII.

The Sympathetic Nerves.

The mechanism of the muscle pump for the return of venous blood from the limbs, which was mentioned in the last chapter, is a part, and only a very small part, of that complex machinery which adapts the circulation to the functional demands of any part undergoing varying phases of activity. Beyond the crude driving power of the heart muscle on the arterial blood, and the influence of the respiratory movements and muscular contractions on the return of the venous blood, there is needed a more subtle influence to regulate the force and rate of the heart, the bore of the blood-vessels, and so the pressure under which the circulation is maintained. This more subtle influence is afforded by the system of nerves known as the sympathetic or autonomic nervous system.

Although the regulation of the circulation and its adaptation to temporary stress is but a part of the functions of this complex system of nerves, there is every reason to believe that it is its oldest and most outstanding *rôle*. The sketch of the sympathetic nerves that will be given here must of necessity be brief, and in many details it must be taken as merely speculative, for a proper understanding of the system as a whole has yet to be arrived at, and it may be said that there are few gaps in anatomical knowledge so apparent and so in need of being filled as the precise details of the sympathetic supply of the limbs and the whole functions of this system apart from its purely visceral aspect.

Primitively, from the point of view of phylogeny, ontogeny, and function, the sympathetic nervous system is in the most intimate relation with certain pigmented cells—known as the chromaffin cells—which constitute the elements of the ductless gland known as the adrenal. The adrenal gland is a body which produces an internal secretion (the commercial suprarenal

extract) which, like the sympathetic nerves, and in conjunction with their influence, acts upon the circulatory system and raises the blood pressure.

In the adult human being the chromaffin cells are found mainly in the medulla of the suprarenal bodies and the sympathetic nerve cells in the various ganglia of the sympathetic chain and visceral plexuses ; but both sets of cells have merely wandered from the central nervous system to these sites in the process of development.

We have already seen that the parent cell of the lowest motor neuraxon is situated, as an anterior horn cell, within the tissues of the spinal cord, but that the similar cell for the sensory neuraxon has migrated from the substance of the spinal cord to the posterior root ganglion. The sympathetic cells have undergone a still greater migration, and have taken up their position in a series of outlying ganglia, strung as beads along the sympathetic chain, scattered in the visceral plexuses or on the walls of viscera, or even being segregated in a so-called ductless gland. Such is the essential nature of the sympathetic nervous system ; its ganglion cells have wandered from the axis of the central nervous system where they were begot, and have taken up stations in outlying parts. In this way a system of nerves so divorced from the central nervous system as to have been considered different in origin and in nature has been laid down. The separation of the sympathetic from the spinal or somatic system of nerves is, however, more apparent than real, and it is not at all impossible that time will show that some of the functions at present considered as being essentially the property of somatic spinal nerves are, in reality, subserved by the sympathetic system.

Since every sympathetic ganglion cell has wandered from some part of the central nervous system to its adult outlying station, it is but natural that it should be tethered to, and retain connection with, the central nervous system by a nerve fibre of some kind. This nerve fibre, which connects the sympathetic ganglion cell with the central nervous axis, may be regarded as a spinal tract drawn out from the cord as the cell wandered away from its parent site. Such fibres are known as pre-ganglionic

fibres or white rami communicantes. They leave the cord by way of the roots (mainly by the anterior root) of the spinal nerves and, freeing themselves from this connection, travel for varying distances to a sympathetic ganglion, where they come into connection with the nerve cells of the ganglion. These pre-ganglionic fibres are of small bore, and for the most part possess that protective sheath known as the medullary or myelin sheath which is present in the typical somatic spinal nerves, and which gives them the white colour justifying the name of white rami communicantes. The course of the pre-ganglionic fibres, or, as we may term them, upper neuron sympathetic fibres, within the central nervous system is by no means so definitely determined as is the case with somatic or spinal nerves proper. They have been traced to nerve cells of the grey matter of the lateral horn of the cord by practically all observers. Gaskell, Onuf, and Collins have traced them in addition to the dorsal nuclear cells (Clarke's column), and Scaffidi and Biedl have also observed them to end in cells of the anterior column.

Now these pre-ganglionic fibres do not pass from the spinal cord by the roots of all the issuing spinal nerves. There is not a sympathetic outflow distributed evenly over all regions of the spinal cord, but it is concentrated upon a comparatively few segments. All those pre-ganglionic fibres which join the great ganglionated chain known as the sympathetic system proper are derived from that limited area of the cord comprised between the first or second thoracic and the first or second lumbar spinal nerves. Only the nerves issuing over this interval of the cord, therefore, give off from their roots the leash of fine medullated fibres constituting the anatomical white rami communicantes.

An outflow of fibres similar in general disposition takes place from certain cranial and lower sacral nerves. The fibres from these sources do not join the ganglionated cord of the sympathetic, but pass as pre-ganglionic fibres to distal visceral ganglia, where they make connection with the ganglion cells and from which they are distributed as post-ganglion fibres—the para-sympathetic nerves of the head and pelvis. The para-sympathetic system does not directly concern us here, and will not be further discussed.

It is therefore apparent that the sympathetic outflow does not occur, or at any rate does not pass to the ganglia of the sympathetic chain, in those regions of the cord from which the great limb plexuses are derived. We may summarise by saying that the upper neuron of the true sympathetic system consists, as far as its connections are at present determined, of a cell in the grey matter of the lateral horn, a neuraxon which leaves the spinal cord in the quiet interval between the limb plexuses and passes along the roots of a thoracic nerve, leaving this nerve as a white ramus communicans or pre-ganglionic fibre. The pre-ganglionic fibre runs a course of varying distance and ultimately ends by coming into contact with one or more nerve cells situated in a ganglion of the sympathetic chain.

From the multipolar nerve cell of the sympathetic ganglion a new neuraxon arises, and, as a rule, these new neuraxons are devoid of the medullary or myelin sheath which gives the white colour to nerves. It is for this reason that the sympathetic fibres of the lower neuron are typically grey and semi-transparent in appearance and are so exceedingly difficult to trace by gross anatomical methods among the tissues of the body. Some of these post-ganglionic fibres pass back to the spinal nerves in the grey rami communicantes, and are presumably distributed with the terminals of these nerves. Some of them pass to the vessels and are carried to outlying parts along their walls, and some pass straight to glands or involuntary muscles which they innervate. Although only those nerves in the interval between the limb plexuses give off white rami communicantes or pre-ganglionic fibres, every spinal nerve in the series receives its contribution of post-ganglionic fibres by way of a grey ramus communicans. That is to say, although sympathetic pre-ganglionic fibres only issue by a limited number of nerve roots, post-ganglionic fibres of distribution pass to all the nerves of the cerebro-spinal system. It was this widespread series of communication with other nerves which led to Winslow, of Paris (1669—1760), giving this system its modern name. These nerves had previously been known as the nervi intercostales, a name to which Winslow rightly objected, and he says ("Anatomy," Sect. VI., p. 94): "I believe the name of Sympathetici Majores, or Maximi, will

be more proper, because of their frequent communications with almost all the other principal nerves of the Body." But though the spinal nerves receive a very definite share of these fine non-medullated branches of distribution, we must not regard this as their only method of traversing the tissues of the body. Many are probably distributed by the blood-vessels in the limbs, as they are well known to be in the visceral cavities, and the course of others most likely still awaits solution.

Now the functions of the sympathetic nerves which we have so far described are well known, for we have so far considered fibres which are motor in function or efferent in impulse-flow. In brief, these fibres activate a wide series of tissues without the intervention of any conscious volition. They dilate the pupil of the eye, produce "goose skin" on the surface of the body, erect the hairs, and produce a secretion from the sweat glands. They quicken the beat of the heart, act on the muscle of the vessel walls, raise the blood pressure, and determine the flow of blood to the muscles, the lungs and the brain, instead of to the vessels of the alimentary canal. They act upon the glands of internal secretion, and on the metabolism generally in such a way as to render the best possible service to the organs called upon for bodily defence. Obviously, the whole of this activity is, as Crile has pointed out, and as Langdon Brown has recently made clear (*Lancet*, 1919, p. 827, etc.), a "mechanism of self-defence." It is an involuntary activity called forth in response to fear or pain, and it fits the animal for the struggle which in animal life is likely to follow the receipt of an unpleasant sensory impression.

But when we turn to the afferent or sensory side of the sympathetic system we find that, despite the work which has been done in careful laboratory investigations, our knowledge is strikingly scanty. Sensory nerve endings have been described by many observers in viscera which have a sympathetic supply; in fact, there are few viscera in which free sensory nerve endings of fibres presumably belonging to this system have not been recorded at some time or other. The details as to the course of these fibres are extremely meagre. The fibres themselves are medullated,

they are larger than the ordinary pre-ganglionic sympathetic fibres, and they apparently make no connection with sympathetic ganglion cells, but pass direct to the cord and enter it " mainly through the white rami communicantes " (Huber).* But these free sensory nerve endings are not the only sensory terminals of the sympathetic nerves in the viscera, for it is well established that the Pacini-Vater corpuscles in the mesentery, retro-peritoneal tissue and other sites in the visceral cavities are the end-organs of this system of nerves. Since this is so, there would seem to be every reason to suppose that the similar bodies, which, as we have seen, exist in large numbers upon the digital nerves, are also the terminals of sympathetic sensory nerves. We know that there are efferent sympathetic fibres passing into the limb of the post-ganglionic grey communicantes to the nerves of the brachial plexus; it is therefore extremely probable that there are also afferent sympathetic fibres in the limb, part at least of which find their end-organs in the Pacini-Vater bodies.

But we lack precise knowledge as to the actual distribution in the limb of either of these sets of fibres. We know that effects which in other parts of the body are known to be produced by efferent sympathetic fibres are brought about by affections of the median nerve especially, and by the ulnar to a lesser degree. Again, in the lower extremity sympathetic effects are evoked mainly by affections of the internal popliteal nerve, and we may therefore assume that these nerves carry a considerable proportion of the limb sympathetic efferents. From the large numbers of Pacini-Vater corpuscles which crowd their terminals we would also suppose the same nerves to be the agents for carrying a large complement of the afferent sympathetics of the limb. The afferent sympathetic fibres from the viscera are said to reach their destination in the cord " mainly through the white rami communicantes," but such a route is obviously not open to them in the case of the nerve of the limb plexuses. In dealing with the sensory pathways we have noted that the fibres of the posterior root are not all of one size, but some of the fibres which

* "The Morphology of the Sympathetic System," XVIIth International Congress of Medicine, 1913, Sect. 1, Part 1, p. 211.

remain in a very fairly distinct bundle are markedly smaller than the usual spinal nerve fibres. These fine fibres, on reaching the cord, run to its lateral aspect, unlike the larger fibres which run to the posterior column, and it is extremely probable that these fine fibres are the afferent sensory elements of the sympathetic system of the limb.

The reason why there should be such a strong individuality in sympathetic qualities manifested by the median and the internal popliteal nerve is difficult to guess. Two facts which have previously been mentioned may, however, be linked together. We have noted that in the visceral cavities sympathetic nerves are commonly distributed along the course of vessels, and we have seen that the original course of the main arteries of the limbs was along the course of the median and internal popliteal nerves. With these nerves there still run the degenerated remains of the ancestral arteries, and it is not impossible that their ancient complement of sympathetic fibres is added as an undue burden to the nerves with which they become incorporated.

Granting that sympathetic sensory nerves exist in the limbs and follow some such course as we have indicated, it still remains to determine what element of sensation may be regarded as their especial province. As Head has said (*op. cit.*, "Brain," 1918, p. 191): "the internal organs are supplied from the protopathic system; there is no controlling epicritic mechanism." But we know that the internal organs are supplied from the anatomical sympathetic system, and so the physiological protopathic may well be the anatomical afferent sympathetic.

This is a highly significant observation, for, as we have seen, protopathic sensibility is a primitive, crude, diffuse sensation of pain or discomfort. Protopathic sensibility warns the animal that it is being hurt, but gives no very precise information as to the exact discrimination or localisation of the actual noxious stimulus. This is the kind of sensation which one would look to meet as the sensory excitor of the well-known sympathetic response. That protopathic sensibility, even in the limbs, is a function of afferent sensory nerves of the sympathetic system is a view which much recent work of physiologists is tending to

establish.* It is obvious that here our knowledge of function is in grave danger of outrunning our knowledge of structure ; and to those who still consider that human anatomy is an exhausted subject we would recommend an investigation of the sympathetic innervation of the limbs.

* See especially Ranson, S. W., *American Jour. Phys.*, Vol. 40, 1916, pp. 571—584.

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